LOCATING SLIPPERY HIGHWAY SURFACES THROUGH ACCIDENT REPORT ANALYSIS

FEBRUARY 1960

NO. 6

by

V. G. STOVER

Joint Highway Research Project

PURDUE UNIVERSITY
LAFAYETTE INDIANA

Final Report

TO: K. B. Woods, Director
Joint Highway Research Project

March 2, 1960

FROM: H. L. Michael, Assistant Director
Joint Highway Research Project

File: 8-5-5
Project: C-36-59E

Attached is a final report entitled, "Locating Slippery Highway Surfaces Through Accident Report Analysis" by Vergil G. Stover, Graduate Assistant on our staff. The report is a summary of research which Mr. Stover also utilized for his thesis for an MSCE degree. The research was directed by Professor H. L. Michael.

The attached report contains several important recommendations relative to the location of slippery sites on Indiana highways. It presents a practical, economical and reliable method for determining such sites and for determining their priority for "deslicking". The method can be applied with a minimum of expense and personnel and the information required is already being collected on the accident reports. The application of the method suggested in the attached report and the "deslicking" of the slippery sites found by its use should contribute in a major way to the reduction of accidents on Indiana highways.

A technical paper will be prepared from this research and is proposed for presentation at the Purdue Road School in April. Presentation is also planned for the Highway Research Board in January 1961.

The report is presented for the record.

Respectfully submitted,

H. L. Michael

H. L. Michael, Secretary

HLM:kmc

Attachment

cc: F. L. Ashbaucher
J. R. Cooper
W. L. Dolch
W. H. Goetz
F. F. Havey
G. A. Leonards
J. F. McLaughlin
R. D. Miles
R. E. Mills
C. E. Vogelgesang
J. L. Waling
J. E. Wilson
E. J. Yoder
G. A. Hawkins (M. B. Scott)

Final Report

LOCATING SLIPPERY HIGHWAY SURFACES THROUGH ACCIDENT REPORT ANALYSIS

by

V. G. Stover
Graduate Assistant

Joint Highway Research Project
File: 8-5-5
Project: C-36-59E

Purdue University
Lafayette, Indiana

March 2, 1960

ACKNOWLEDGMENTS

The author wishes to express his sincerest appreciation to Professor Harold L. Michael, Assistant Director, Joint Highway Research Project, for his invaluable assistance in all phases of the study and in the preparation and review of the manuscript; to Dr. Irving W. Burr, Department of Mathematics and Statistics for his advice on the statistical design of the study and analysis of the data and for his review of the manuscript; to Mr. Carl E. Vogelgesang, Chief Engineer, and Mr. F. F. Havey, Engineer of Materials and Tests, State Highway Department of Indiana, whose cooperation made the collection of the field skid data possible; and to the other members of the highway department for their assistance in the conduct of the field skid tests.

Acknowledgment is also made to Superintendent Harold S. Zies and Major Paul T. Beverforden, Indiana State Police, for their excellent cooperation and interest throughout the conduct of the study; and to the other members of the Indiana State Police and the staff of the Joint Highway Research Project for their assistance at various stages of the study.

Digitized by the Internet Archive
in 2011 with funding from
LYRASIS members and Sloan Foundation; Indiana Department of Transportation

http://www.archive.org/details/locatingslippery06stov

TABLE OF CONTENTS

Page

LIST OF TABLES v

LIST OF FIGURES. vi

ABSTRACT vii

INTRODUCTION 1

  Skid Resistance. 1

  Purpose. 3

PREVIOUS INVESTIGATIONS. 5

  Locating Slippery Sites. 5

  Skidding Resistance Measurement and Skidding Characteristics . 6

SKIDDING AS A FACTOR IN ACCIDENTS. 7

  Reporting of Accidents 7

  Skidding in Accidents on Dry, Wet, and Icy Roads 7

ACCIDENT REPORT INVESTIGATION. 11

  Evaluation of Low Frequency Accident Sites 11

  Limits of Study. 16

  Analysis of Accident Reports 17

FIELD SKID INVESTIGATION 33

  Scope. 33

  Test Sites, Equipment, and Procedure 33

SPEED AND VOLUME INVESTIGATION 40

Page

Scope. 40
Speed Sites, Equipment, and Procedure. 40
Traffic Volumes. 43
DISCUSSION OF RESULTS. 44
Factors Affecting the SSR. 44
Related Correlation. 56
SUMMARY AND RECOMMENDATIONS. 58
POSSIBLE PROCEDURES FOR A STATE-WIDE ROUTE SKID ANALYSIS 61
Information Necessary. 61
Accident Location Map. 61
Mechanical Methods 65
BIBLIOGRAPHY 67
APPENDIX 71

LIST OF TABLES

Table Page

1. Skidding as a Factor in Reported Accidents. 10

2. Table for the Determination of the Significant Skidding Rate 13

3. Distribution of the SSR by Road Length (Wet Surface Condition) for the Ten Counties Studied 24

4. List of Road Lengths Which Have a Significant Skidding Rate of That Indicated or Higher. 26

5. Location of Accident Clusters Which Have a Significant Skidding Rate of at Least That Indicated. 29

6. Summary of Skid Tests on Sample Road Lengths. 38

7. Summary of the Simple Correlation Coefficients. 51

LIST OF FIGURES

Figure Page

1. Investigator's Accident Report Form 8
2. Location of Counties Studied. 19
3. Typical County Accident Location Map - Porter County. . . 21
4. Typical County Accident Location Map - Grant County . . . 22
5. Scatter Diagram of the Distance Required to Stop and the Significant Skidding Rate by Road Lengths 45
6. Scatter Diagram of the Mean Over-All Speed and the Significant Skidding Rate by Road Lengths 46
7. Scatter Diagram of the Average Annual Daily Traffic and the Significant Skidding Rate by Road Lengths 47
8. Scatter Diagram of the Distance Required to Stop and the Significant Skidding Rate by Accident Clusters. . . . 48
9. Scatter Diagram of the Mean Over-All Speed and the Significant Skidding Rate by Accident Clusters. 49
10. Scatter Diagram of the Average Annual Daily Traffic and the Significant Skidding Rate by Accident Clusters. . . . 50

ABSTRACT

Stover, Vergil G., MSCE, Purdue University, June 1959. Locating Slippery Highway Surfaces Through Accident Report Analysis. Major Professor: Harold L. Michael.

Several methods of field testing have been developed and used to measure the slipperiness of pavement surfaces. However, little research has been done in regard to locating slippery sites from accident reports or in the determination of sites at which field testing should be conducted.

This thesis reports the results of a study concerned with the utilization of accident analysis for the location of slippery portions of highways. All rural US and State marked routes in ten Indiana counties were analyzed on the basis of accident clusters and accidents occurring on a single highway within a particular township. Statistical methods were then employed to determine, for each location, the significant percentage of all wet surface accidents in which skidding occurred. Field tests to determine the slipperiness of the surfaces were conducted on a sample composed of twenty-one locations. A test vehicle utilizing the stopping distance method was employed in these tests. The mean over-all speeds and the average annual daily traffic were also obtained for the sample locations.

The study indicates that there is a very significant correlation

between skidding accidents and the slipperiness of the surface. It further indicates that accident report analysis can reliably be employed to locate slippery highway surfaces.

INTRODUCTION

Skid Resistance

It is generally agreed that a wet pavement surface exhibits less resistance to skidding than does the same surface in a dry condition. This difference, at least in part, is due to the lubricating action of the water or the water mixed with oil drippings. Ice and snow are special conditions and as such do not reflect any skid characteristic of the pavement surface. Therefore, it is the wet surface condition that is critical in determining the minimum level of skid resistance that is available on a particular surface. Under this unfavorable road condition, a smaller proportion of the vehicle-driver units are able to execute a successful solution to a presented problem.

Excessive skidding on wet surfaces might be anticipated on highways where the reduced resistance to skidding is less than that necessary to permit the vehicle operator to perform a required maneuver (such as a relatively sharp turn or a normal stop). It may also be expected where a pavement surface which exhibits a high resistance to skidding, to which the drivers have become accustomed through a considerable distance of travel, is followed by a surface which presents a low resistance to skidding. On the other hand, these same locations may not indicate any particular skidding problem when the surface is dry.

It should not be construed that the highway is the only part of

the driver-vehicle-road system that contributes to skidding. The driver may be at fault through the application of improper driving techniques and the vehicle through unbalanced brakes and/or smooth tires, etc. The road, however, is the component over which the highway engineer has considerable and direct control. Through the employment of sound engineering procedures, the engineer can minimize the deficiencies of the driver and the vehicle. However, the effective and efficient use of this control over the highway, through "de-slicking" procedures, requires that those locations, which are slippery, be identified and evaluated at the earliest possible date.

At present, the only method used by the State Highway Department of Indiana for evaluating slippery locations is the expensive and time consuming vehicle stopping distance procedure. The value of this method lies in its use to measure, and compare, the skid resistance of pavement surfaces. It does not, however, locate those sites which are suspected of being slippery (i.e. some other source of information must dictate the locations at which the tests should be conducted).

A procedure that would systematically evaluate the skid resistance of the entire state highway system and would indicate those locations at which the surface is "slick" would be of considerable value. It would also be desirable if this method could eliminate the need for extensive field tests and would necessitate a bare minimum of additional labor. Accident records can be a fruitful source of information; when properly analyzed, they might be used as an aid in locating slippery lengths of highway.

The number of accidents and the condition of the pavement surface

at the time these accidents occurred is obtainable from the accident reports. However, in order to compare the number of accidents by surface condition occurring on various highways, it is necessary to consider the amount of traffic which traversed these highways while the surface was dry, wet, or icy (i.e., covered with ice or snow). Unfortunately, the vehicle miles traveled on a length of roadway under the different surface conditions is unknown. If the total number of accidents occurring while the surfaces were dry, wet, or icy is used as a measure of the exposure rate, a measure of the relative risk of skidding can be obtained by comparing the percentage of accidents involving skidding. This presumes that there must be a relationship between the total number of accidents occurring while the surface was dry, wet, or icy and the proportion of the time the surfaces were in each of these conditions as well as the amount of traffic using the road while these conditions prevailed. Throughout this report, the percentage of accidents in which skidding was involved will be referred to as the skidding rate.

Purpose

This study was an attempt to utilize accident reports to determine the location of slippery highway sites. The state highways in ten counties of Indiana were analyzed in this research. A method of analysis developed by the Road Research Laboratory of Great Britain was employed to evaluate the skidding rates for the wet surface condition on the several lengths of highway within these counties. On the basis of this analysis, the relative slipperiness of the various lengths of highway was established.

Obviously, some manner of control was desirable to check the reliability of the method. The "acid test" would have been to apply corrective measures at the locations that were determined to be slippery and then to reevaluate the locations on the basis of the accident history during an after-study period. However, another method which requires a shorter period of time and which yields valuable information in its own right was also available. This method was to conduct field skid tests on a statistically selected sample of highway locations.

The field tests provided the data required to perform a regression-correlation analysis so as to determine the relationship between the slipperiness of pavement surfaces and the skidding accidents occurring on these surfaces when wet. The correlation coefficient thus calculated is a measure of the effectiveness of accident report analysis in determining the relative slipperiness of pavement surfaces.

There is some indication that factors other than the slipperiness of the surface have noticeable affect upon the percentage of accidents which involve skidding. This study also attempted to determine the correlation, if any, that exists between traffic volumes, vehicular speeds, and skidding accidents on wet surfaces.

The procedures utilized in the analysis of the accident reports, the conduct of the field tests, and the sources of other data are discussed in detail in later sections of this report.

PREVIOUS INVESTIGATIONS

Locating Slippery Sites

The broad aspect of skidding has received considerable attention in the United States as well as abroad. The methods of evaluating skidding accident locations have been largely restricted to field measurement procedures. With respect to skidding, the use of accident reports has been largely limited to the tabulation of skidding accident data.

The analysis of accident records as an aid in locating slippery lengths of highway has not, to the author's knowledge, been studied in the United States. The only extensive work performed in this area was conducted by C. G. Giles and Barbara E. Sabley of the Road Research Laboratory in Great Britain (1, 2)*. In their investigations, the use of statistical methods for the analysis of highway sites which had a low frequency of skidding accidents were developed. These statistical methods for determining when the frequency of skidding accidents is unduly high have been extensively employed in that country. After-studies conducted at sites that have been so located and then "de-slicked" showed a substantial reduction in skidding accidents as well as in total accidents (3).

---

* Numbers in parentheses refer to listing in the bibliography.

Skidding Resistance Measurement and Skidding Characteristics

Much attention has been focused on the measurement of resistance to skidding. Field investigations have employed the stopping distance, towed trailer, and decelerometer methods. Other investigations have revealed information about the skidding characteristics of various pavement types and surface conditions and the effects of roadside development as well as other factors. A more limited amount of research has been conducted to determine the relative frequency of skidding accidents.

A wealth of skidding information has been collected and reported in the literature. The complete coverage of all phases of skidding is outside the scope of this investigation; however, much of this information is of general interest and several of these studies are listed in the bibliography under general references. The Proceedings of the First International Skid Prevention Conference is the largest single source of skidding information.

Laboratory tests of the aggregate and of paving mixtures have been developed to reveal information concerning the effect of polishing and the predictable skidding characteristics of the pavement surface. "De-slicking" methods and the application of "de-slicking" treatments have also been the subject of some research. A partial list of these investigations is also included in the general references.

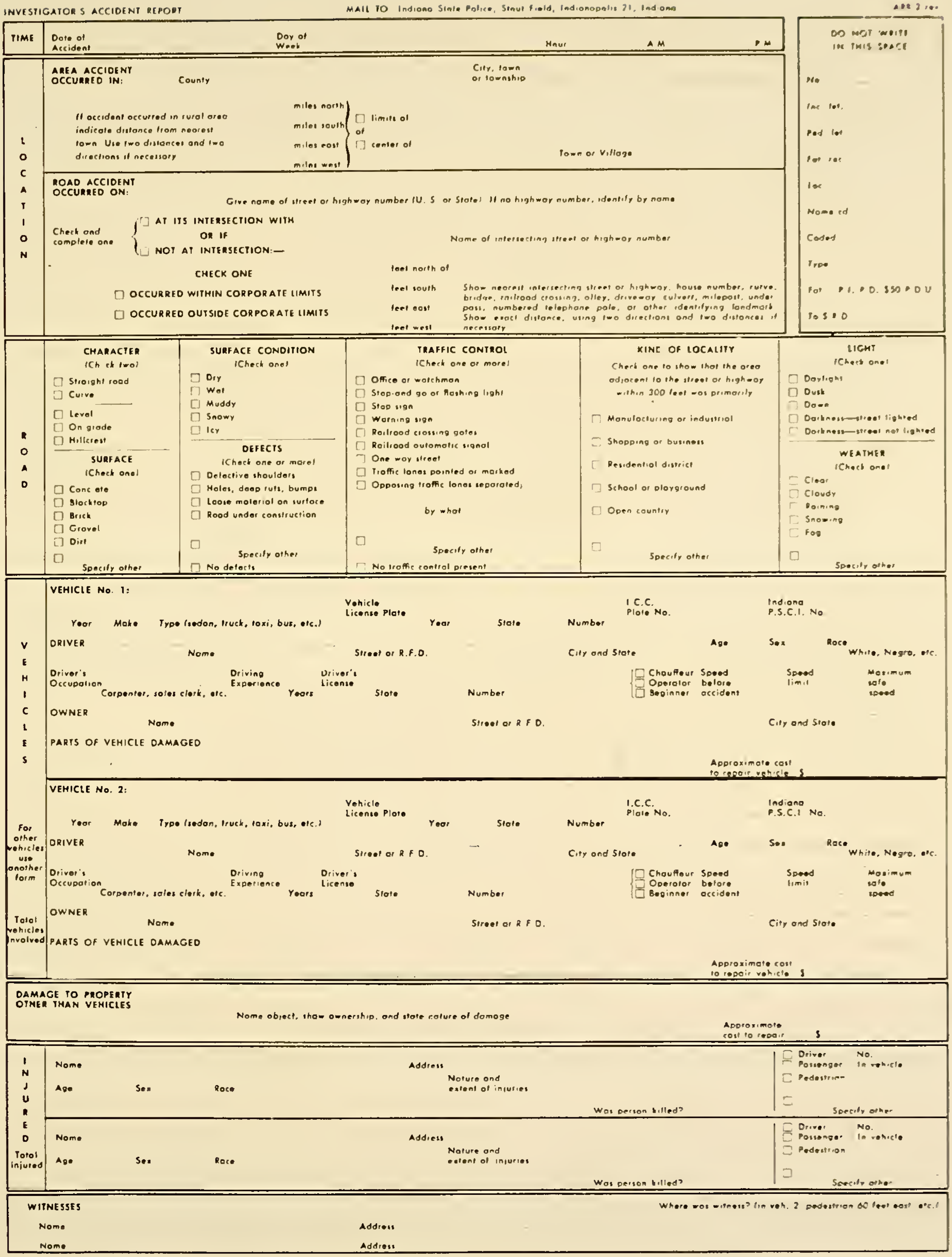
SKIDDING AS A FACTOR IN ACCIDENTS

Reporting of Accidents

Indiana law requires every driver of a motor vehicle involved in an accident which results in death, injury, or property damage of fifty dollars or more, to submit a report within five days of the accident. In addition, an investigator's report is submitted on all accidents which are investigated by a police officer. Skidding is reported as occurring before and/or after the brakes are applied. Figure 1 shows the accident report form presently used by the Indiana State Police.

Skidding in Accidents on Dry, Wet, and Icy Roads

The over-all problem of skidding in accidents occurring in 1958, as determined from the reported accidents in ten counties of Indiana, is summarized in Table 1.



INVESTIGATOR'S ACCIDENT REPORT
MAIL TO Indiana State Police, Stout Field, Indianapolis 21, Indiana
APR 2 rev

TIME Date of Accident Day of Week Hour A M P M

DO NOT WRITE IN THIS SPACE
No
Inc tot.
Ped tot
Fat rec
Inc
Name rd
Coded
Type
Fat P I. P D. $50 P D U
To $ P D

LOCATION

AREA ACCIDENT OCCURRED IN: County City, town or township

If accident occurred in rural area indicate distance from nearest town. Use two distances and two directions if necessary
miles north / miles south / miles east / miles west of ☐ limits of ☐ center of Town or Village

ROAD ACCIDENT OCCURRED ON: Give name of street or highway number (U. S or State) If no highway number, identify by name

Check and complete one
☐ AT ITS INTERSECTION WITH
OR IF
☐ NOT AT INTERSECTION:—
Name of intersecting street or highway number

CHECK ONE
☐ OCCURRED WITHIN CORPORATE LIMITS
☐ OCCURRED OUTSIDE CORPORATE LIMITS

feet north of
feet south
feet east
feet west
Show nearest intersecting street or highway, house number, curve, bridge, railroad crossing, alley, driveway culvert, milepost, under pass, numbered telephone pole, or other identifying landmark Show exact distance, using two directions and two distances if necessary

ROAD

CHARACTER (Check two)
☐ Straight road
☐ Curve
☐ Level
☐ On grade
☐ Hillcrest

SURFACE (Check one)
☐ Concrete
☐ Blacktop
☐ Brick
☐ Gravel
☐ Dirt
☐ Specify other

SURFACE CONDITION (Check one)
☐ Dry
☐ Wet
☐ Muddy
☐ Snowy
☐ Icy

DEFECTS (Check one or more)
☐ Defective shoulders
☐ Holes, deep ruts, bumps
☐ Loose material on surface
☐ Road under construction
☐ Specify other
☐ No defects

TRAFFIC CONTROL (Check one or more)
☐ Office or watchman
☐ Stop-and go or flashing light
☐ Stop sign
☐ Warning sign
☐ Railroad crossing gates
☐ Railroad automatic signal
☐ One way street
☐ Traffic lanes painted or marked
☐ Opposing traffic lanes separated; by what
☐ Specify other
☐ No traffic control present

KIND OF LOCALITY
Check one to show that the area adjacent to the street or highway within 300 feet was primarily
☐ Manufacturing or industrial
☐ Shopping or business
☐ Residential district
☐ School or playground
☐ Open country
☐ Specify other

LIGHT (Check one)
☐ Daylight
☐ Dusk
☐ Dawn
☐ Darkness—street lighted
☐ Darkness—street not lighted

WEATHER (Check one)
☐ Clear
☐ Cloudy
☐ Raining
☐ Snowing
☐ Fog
☐ Specify other

VEHICLES

VEHICLE No. 1:
Year Make Type (sedan, truck, taxi, bus, etc.) Vehicle License Plate Year State Number I.C.C. Plate No. Indiana P.S.C.I. No
DRIVER Name Street or R.F.D. City and State Age Sex Race White, Negro, etc.
Driver's Occupation Carpenter, sales clerk, etc. Driving Experience Years Driver's License State Number ☐ Chauffeur ☐ Operator ☐ Beginner Speed before accident Speed limit Maximum safe speed
OWNER Name Street or R F D. City and State
PARTS OF VEHICLE DAMAGED
Approximate cost to repair vehicle $

VEHICLE No. 2:
Year Make Type (sedan, truck, taxi, bus, etc.) Vehicle License Plate Year State Number I.C.C. Plate No. Indiana P.S.C.I No.
DRIVER Name Street or R F D. City and State Age Sex Race White, Negro, etc.
Driver's Occupation Carpenter, sales clerk, etc. Driving Experience Years Driver's License State Number ☐ Chauffeur ☐ Operator ☐ Beginner Speed before accident Speed limit Maximum safe speed
OWNER Name Street or R F D. City and State
PARTS OF VEHICLE DAMAGED
Approximate cost to repair vehicle $

For other vehicles use another form

Total vehicles involved

DAMAGE TO PROPERTY OTHER THAN VEHICLES
Name object, show ownership, and state nature of damage
Approximate cost to repair $

INJURED

Name Address ☐ Driver ☐ Passenger ☐ Pedestrian No. In vehicle
Age Sex Race Nature and extent of injuries
Was person killed? ☐ Specify other

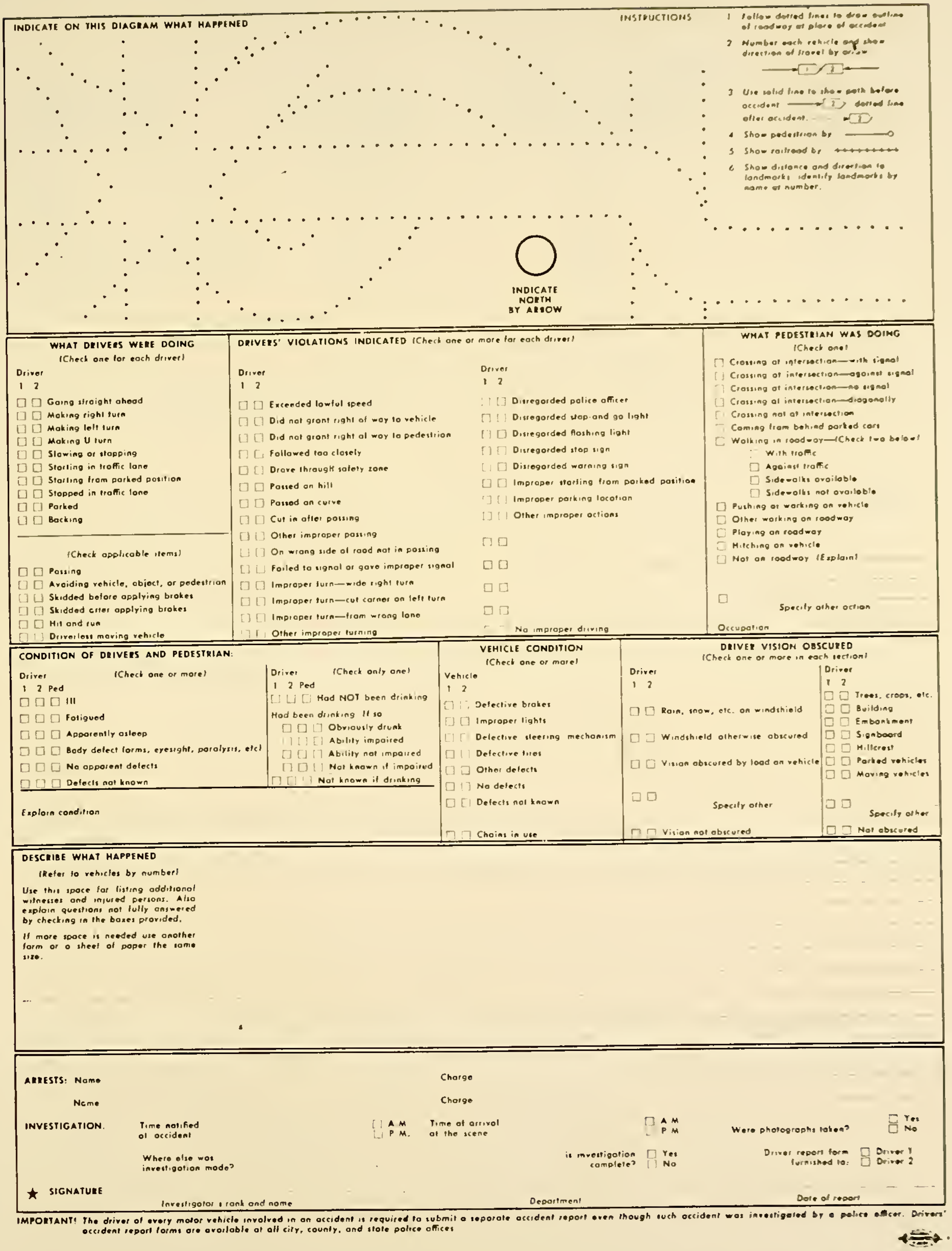
Name Address ☐ Driver ☐ Passenger ☐ Pedestrian No. In vehicle
Age Sex Race Nature and extent of injuries
Was person killed? ☐ Specify other

Total injured

WITNESSES Where was witness? (in veh. 2 pedestrian 60 feet east etc.)
Name Address
Name Address

INVESTIGATOR'S ACCIDENT REPORT FORM

FIGURE 1(a)



INDICATE ON THIS DIAGRAM WHAT HAPPENED

INSTRUCTIONS
1 Follow dotted lines to draw outline of roadway at place of accident
2 Number each vehicle and show direction of travel by arrow
3 Use solid line to show path before accident; dotted line after accident.
4 Show pedestrian by
5 Show railroad by
6 Show distance and direction to landmarks; identify landmarks by name or number.

INDICATE
NORTH
BY ARROW

WHAT DRIVERS WERE DOING
(Check one for each driver)

Driver
1 2
☐ ☐ Going straight ahead
☐ ☐ Making right turn
☐ ☐ Making left turn
☐ ☐ Making U turn
☐ ☐ Slowing or stopping
☐ ☐ Starting in traffic lane
☐ ☐ Starting from parked position
☐ ☐ Stopped in traffic lane
☐ ☐ Parked
☐ ☐ Backing

(Check applicable items)
☐ ☐ Passing
☐ ☐ Avoiding vehicle, object, or pedestrian
☐ ☐ Skidded before applying brakes
☐ ☐ Skidded after applying brakes
☐ ☐ Hit and run
☐ ☐ Driverless moving vehicle

DRIVERS' VIOLATIONS INDICATED (Check one or more for each driver)

Driver
1 2
☐ ☐ Exceeded lawful speed
☐ ☐ Did not grant right of way to vehicle
☐ ☐ Did not grant right of way to pedestrian
☐ ☐ Followed too closely
☐ ☐ Drove through safety zone
☐ ☐ Passed on hill
☐ ☐ Passed on curve
☐ ☐ Cut in after passing
☐ ☐ Other improper passing
☐ ☐ On wrong side of road not in passing
☐ ☐ Failed to signal or gave improper signal
☐ ☐ Improper turn—wide right turn
☐ ☐ Improper turn—cut corner on left turn
☐ ☐ Improper turn—from wrong lane
☐ ☐ Other improper turning

Driver
1 2
☐ ☐ Disregarded police officer
☐ ☐ Disregarded stop-and go light
☐ ☐ Disregarded flashing light
☐ ☐ Disregarded stop sign
☐ ☐ Disregarded warning sign
☐ ☐ Improper starting from parked position
☐ ☐ Improper parking location
☐ ☐ Other improper actions
☐ ☐
☐ ☐
☐ ☐
☐ ☐
☐ ☐ No improper driving

WHAT PEDESTRIAN WAS DOING
(Check one)
☐ Crossing at intersection—with signal
☐ Crossing at intersection—against signal
☐ Crossing at intersection—no signal
☐ Crossing at intersection—diagonally
☐ Crossing not at intersection
☐ Coming from behind parked cars
☐ Walking in roadway—(Check two below)
  ☐ With traffic
  ☐ Against traffic
  ☐ Sidewalks available
  ☐ Sidewalks not available
☐ Pushing or working on vehicle
☐ Other working on roadway
☐ Playing on roadway
☐ Hitching on vehicle
☐ Not on roadway (Explain)
☐
Specify other action
Occupation

CONDITION OF DRIVERS AND PEDESTRIAN:

Driver (Check one or more)
1 2 Ped
☐ ☐ ☐ Ill
☐ ☐ ☐ Fatigued
☐ ☐ ☐ Apparently asleep
☐ ☐ ☐ Body defect (arms, eyesight, paralysis, etc)
☐ ☐ ☐ No apparent defects
☐ ☐ ☐ Defects not known

Driver (Check only one)
1 2 Ped
☐ ☐ ☐ Had NOT been drinking
Had been drinking. If so
☐ ☐ ☐ Obviously drunk
☐ ☐ ☐ Ability impaired
☐ ☐ ☐ Ability not impaired
☐ ☐ ☐ Not known if impaired
☐ ☐ ☐ Not known if drinking

Explain condition

VEHICLE CONDITION
(Check one or more)
Vehicle
1 2
☐ ☐ Defective brakes
☐ ☐ Improper lights
☐ ☐ Defective steering mechanism
☐ ☐ Defective tires
☐ ☐ Other defects
☐ ☐ No defects
☐ ☐ Defects not known
☐ ☐ Chains in use

DRIVER VISION OBSCURED
(Check one or more in each section)

Driver
1 2
☐ ☐ Rain, snow, etc. on windshield
☐ ☐ Windshield otherwise obscured
☐ ☐ Vision obscured by load on vehicle
☐ ☐
Specify other
☐ ☐ Vision not obscured

Driver
1 2
☐ ☐ Trees, crops, etc.
☐ ☐ Building
☐ ☐ Embankment
☐ ☐ Signboard
☐ ☐ Hillcrest
☐ ☐ Parked vehicles
☐ ☐ Moving vehicles
☐ ☐
Specify other
☐ ☐ Not obscured

DESCRIBE WHAT HAPPENED
(Refer to vehicles by number)

Use this space for listing additional witnesses and injured persons. Also explain questions not fully answered by checking in the boxes provided.

If more space is needed use another form or a sheet of paper the same size.

ARRESTS: Name — Charge
Name — Charge

INVESTIGATION. Time notified of accident ☐ A.M. ☐ P.M.
Time of arrival at the scene ☐ A.M. ☐ P.M.
Were photographs taken? ☐ Yes ☐ No
Where else was investigation made?
Is investigation complete? ☐ Yes ☐ No
Driver report form furnished to: ☐ Driver 1 ☐ Driver 2

★ **SIGNATURE**
Investigator's rank and name — Department — Date of report

IMPORTANT! *The driver of every motor vehicle involved in an accident is required to submit a separate accident report even though such accident was investigated by a police officer. Drivers' accident report forms are available at all city, county, and state police offices*

INVESTIGATOR'S ACCIDENT REPORT FORM

FIGURE 1(b)

TABLE 1

SKIDDING AS A FACTOR IN REPORTED ACCIDENTS

Condition of Road Surface	Total Number of Accidents	Number of Accidents in Which Skidding Was Involved	Skidding Rate[*]
Dry	1776	713	41
Wet	779	469	60
Icy (i.e. covered with ice or snow)	275	199	72
All conditions	2830	1381	49

---

[*] The number of accidents involving skidding as a percentage of the total number of accidents.

The high percentage of accidents on dry surfaces in which skidding occurred, is not too surprising. This can be explained by the fact that the braking systems on most of the vehicles on the highways of the United States are of sufficient capacity to lock the wheels on all types of pavement surfaces. This is especially true when the driver perceives an accident as being imminent and attempts a "panic" stop. Recent investigations (4) on dry surfaces show that a large proportion of vehicles can lock at least one wheel when braking rapidly and that a high percentage of passenger cars can lock all four wheels.

The accident records indicated that five percent of the accidents occurring on dry pavements involved skidding before the brakes were applied. Skidding before applying the brakes was reported to have occurred in twenty percent of the accidents on wet surfaces.

ACCIDENT REPORT INVESTIGATION

Evaluation of Low Frequency Accident Sites

The skidding rate is a useful method of indicating the relative risk of skidding on dry, wet, and icy surfaces when a large number of accidents has occurred. When a relatively small number of accidents is involved (perhaps less than fifty), the effect of chance occurrence becomes extremely important. Because the accident frequency of the vast majority of accident sites is quite small, some method is necessary to determine when the frequency of skidding accidents is excessive. Such a method must permit the highway engineer to definitely determine when the frequency of skidding accidents on one length of roadway is greater than some acceptable standard or on some other length of highway.

Statistical methods enable the solution of problems of this nature. Since skidding accidents follow a binomial distribution (See Appendix A, Basis of the SSR), the binomial distribution can be employed to make allowance for chance effect. Tables of the Cumulative Binomial Probability Distribution (5) were used to calculate the minimum percentage of wet surface accidents in which skidding was involved with ninety-five percent confidence (i.e. there is only one chance in twenty that the skidding rate is less than this value). This value will henceforth be referred to as the significant skidding rate or the SSR.

The necessity for employing the concept of the SSR is that, as

previously indicated, the relative effect of chance occurrence increases as the frequency decreases. This may be illustrated by the comparison of two accident groupings having the same skidding rate. For example, assume that one group consisted of a total of six wet surface accidents of which three involved skidding and that another group consisted of a total of sixteen accidents of which eight involved skidding. In both cases the skidding rate is fifty percent. However, at the five percent significance level, the SSR of the first group (three skidding accidents out of a total of six) is fifteen percent while the SSR of the second group is twenty-five percent. Thus, it is evident that for higher accident frequencies the confidence interval is smaller (i.e. for a given significance level, the interval that in all probability includes the true skidding rate is smaller).

When only one skidding accident is involved, the SSR is considered to be not significant. For very low frequencies, less than four accidents, a single skidding accident is actually statistically significant, however, the resulting SSR is very low. For example, if skidding is involved in one out of two accidents the SSR, as given by the binomial distribution, would be only two percent. Obviously, practical consideration prevents the application of corrective measures at these locations. Therefore, in the analysis the term not significant or NS is assigned to a single skidding accident.

Table 2 indicates the total number of accidents necessary for various significant skidding rates when the number of skidding accidents is known. This table is most easily used by entering the table in column X with the number of skidding accidents, then reading horizontally to

Number Wet Sur Accident Which Ski Occurr X
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

TABLE 2

TABLE FOR THE DETERMINATION OF THE SIGNIFICANT SKIDDING RATE

Number of Wet Surface Accidents in Which Skidding Occurred X	The Skidding Rate* is significantly greater than the percentage given at the top of the column if the total number of wet surface accidents is less than that given in the body of the table.																					Number of Wet Surface Accidents in Which Skidding Occurred X
	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%	20%	25%	30%	35%	40%	45%	50%	
2	19	13	10	8	7	6	5	5	4	4	4	4	3	3	---	---	---	---	---	---	---	2
3	42	28	22	17	15	13	11	10	9	9	8	7	7	7	5	4	4	4	---	---	---	3
4	69	47	35	29	24	21	18	17	15	14	13	12	11	10	8	7	6	5	5	5	---	4
5	100	67	51	41	34	30	26	23	21	19	18	17	16	15	11	10	8	7	7	6	6	5
6	132	89	67	53	45	39	34	31	28	25	24	22	20	19	15	12	11	9	9	8	7	6
7	166	111	84	67	57	49	43	38	35	32	29	27	25	24	18	15	13	11	10	10	9	7
8	201	135	101	81	68	59	52	46	42	38	35	33	31	29	22	18	15	14	12	11	10	8
9	236	158	119	95	80	69	61	54	49	45	41	38	36	34	26	21	18	16	14	13	12	9
10	273	183	138	111	93	79	70	63	57	51	48	44	41	39	30	24	21	18	16	15	14	10
11	310	208	157	124	105	91	80	71	64	59	54	50	47	44	33	27	23	20	18	17	15	11
12	348	233	175	141	118	101	89	79	72	65	60	56	52	49	37	30	26	23	20	18	17	12
13	387	259	194	156	131	112	99	88	80	73	67	62	57	53	41	34	29	25	22	20	19	13
14	426	284	214	172	144	123	109	97	87	79	73	68	63	59	45	37	31	27	24	22	20	14
15	465	310	234	187	157	135	119	105	95	87	80	74	69	65	49	40	34	30	26	24	22	15
16	504	337	252	203	170	145	128	113	103	94	87	80	75	70	53	43	37	32	29	26	24	16
17	543	364	272	219	183	157	138	122	112	101	93	87	81	75	57	47	40	34	31	28	25	17
18	582	390	293	235	197	169	148	132	120	108	100	93	86	81	61	50	42	37	33	30	27	18
19	623	418	313	250	209	181	159	141	128	116	106	99	92	86	65	53	45	39	35	31	29	19
20	664	445	334	267	224	192	169	151	135	123	113	105	98	92	70	57	48	42	37	33	31	20

X
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44

TABLE 2 (Continued)

X	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%	20%	25%	30%	35%	40%	45%	50%	X
21	706	472	354	284	237	204	179	160	144	131	121	112	103	97	74	60	51	44	39	35	32	21
22	748	500	375	302	251	215	190	169	152	138	125	118	110	102	78	63	54	47	41	37	34	22
23	788	524	396	318	265	227	200	178	161	146	134	124	115	108	82	67	56	49	43	39	36	23
24	829	554	417	334	279	240	209	187	169	154	142	131	122	113	87	70	59	51	46	41	38	24
25	871	580	438	350	292	249	221	197	177	162	148	137	128	120	91	73	62	54	48	43	39	25
26			459	367	307	264	230	205	186	169	157	144	134	125	95	77	65	56	50	45	41	26
27			480	385	321	275	242	214	194	177	163	151	140	131	99	81	68	59	52	47	43	27
28			501	402	335	287	251	224	202	185	170	157	146	136	103	84	71	61	54	49	45	28
29			519	419	349	301	263	233	210	192	177	163	152	142	107	87	74	64	57	51	46	29
30			542	435	364	312	273	243	220	201	184	170	158	148	111	91	77	66	59	53	48	30
31					378	324	284	252	227	207	191	177	164	154	116	94	80	69	61	55	50	31
32					392	336	295	263	236	215	198	183	171	160	121	98	82	71	63	57	51	32
33					406	348	305	271	245	223	204	190	177	165	125	101	85	74	65	59	54	33
34					421	362	316	282	253	230	211	197	183	171	130	104	88	76	68	61	55	34
35					435	375	327	291	263	240	220	203	189	177	133	107	91	79	70	63	57	35
36							338	301	270	246	226	208	195	183	138	111	94	81	72	65	59	36
37							349	310	281	254	233	216	202	188	142	114	97	84	74	67	61	37
38							361	321	288	263	242	223	206	194	147	118	100	87	77	69	63	38
39							370	329	297	270	248	229	212	201	151	122	102	89	79	71	64	39
40							382	341	306	279	255	236	221	205	155	125	105	92	81	73	66	40
41									315	287	263	243	225	210	161	129	108	94	83	75	68	41
42									324	294	270	249	231	217	164	132	111	97	85	77	70	42
43									332	303	278	257	240	223	169	136	114	99	88	79	72	43
44									342	310	285	263	245	228	173	140	117	101	90	81	73	44

X
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

TABLE 2 (Continued)

X	25%	30%	35%	40%	45%	50%	X
45	143	121	103	92	83	75	45
46	147	123	106	95	85	77	46
47	151	126	109	97	87	79	47
48	154	130	112	99	89	81	48
49	157	132	114	101	91	83	49
50	162	135	116	102	93	84	50
51	164	138	120	104	95	86	51
52	168	141	122	107	97	88	52
53	172	144	124	111	99	90	53
54	175	147	127	112	101	92	54
55	180	151	130	114	102	94	55
56	183	153	132	116	104	95	56
57	186	156	134	119	105	97	57
58	191	160	137	121	108	99	58
59	194	162	141	123	111	101	59
60	197	165	143	125	112	102	60
61	201	169	145	128	114	103	61
62	203	172	148	131	116	105	62
63	206	174	151	132	119	107	63
64	209	178	153	134	121	110	64
65	213	181	155	137	122	111	65
66	219	184	159	140	124	113	66
67	222	187	161	142	126	114	67
68	225	191	163	144	129	116	68
69	228	193	166	146	131	119	69
70	231	196	169	149	133	121	70
71	236	199	172	151	134	122	71
72	241	202	174	153	137	123	72
73	244	204	177	155	140	125	73
74	246	206	180	158	141	128	74
75	250	208	182	161	143	131	75
76	254	212	184	162	145	132	76
77	260	216	187	164	147	133	77
78	263	221	191	167	150	135	78
79	265	223	193	170	152	137	79
80	368	225	195	172	153	140	80

* At the 0.05 level of significance (i.e., there is only one chance in twenty that the true skidding rate is less than that indicated)

the column farthest to the right which has a number larger than the total number of accidents occurring. The significant skidding rate is given at the top of this column. For example, if a total of fourteen accidents have occurred on a length of roadway and seven of these accidents involved skidding, the significant skidding rate is twenty-five percent. This means that nineteen times out of twenty we are sure that the true, long term, percentage of wet surface accidents at this location which involve skidding is at least twenty-five percent. If only four of the fourteen accidents had involved skidding, the significant skidding rate would have been ten percent (i.e. ninety-five percent of the time we are sure that the true, long run, percentage of wet surface accidents which involve skidding will be at least ten percent).

Limits of Study

It was anticipated that mechanical methods could be employed in the tabulation of the accident report data. Because the information concerning accidents is transferred to punch cards by the Indiana State Police, it was decided to use the smallest unit for which the locations are coded as the unit of study. This unit is an individual route within a particular township and will be referred to as a "road length" throughout this report.

The use of the road lengths, however, made the employment of a cluster of accidents at a specific location as the unit of study difficult because, as just stated, the detailed location information was not available from the punch cards. However, various changes in the original plan were necessary as the study progressed. Some of these changes, as

explained later, made the use of the accident clusters feasible and, therefore, both road lengths and accident clusters were utilized as units of study.

This study was limited to State and United States marked routes because many county roads have gravel surfaces and were, therefore, outside of the scope of this investigation.

The period of study was restricted to the 1958 calendar year for two main reasons. The first, and perhaps most important, is that recent accident history was deemed preferable. At the time this study was begun only a few months of 1959 had passed and since the accident records are filed by year, it was decided to utilize the preceding full year.

Secondly, as short a period as practicable was felt desirable so as to minimize the number of surfaces that would be altered by resurfacing or reconstruction during the study period. Furthermore, the one year period should be more desirable from a practical application standpoint since accident analysis is presently oriented to this period.

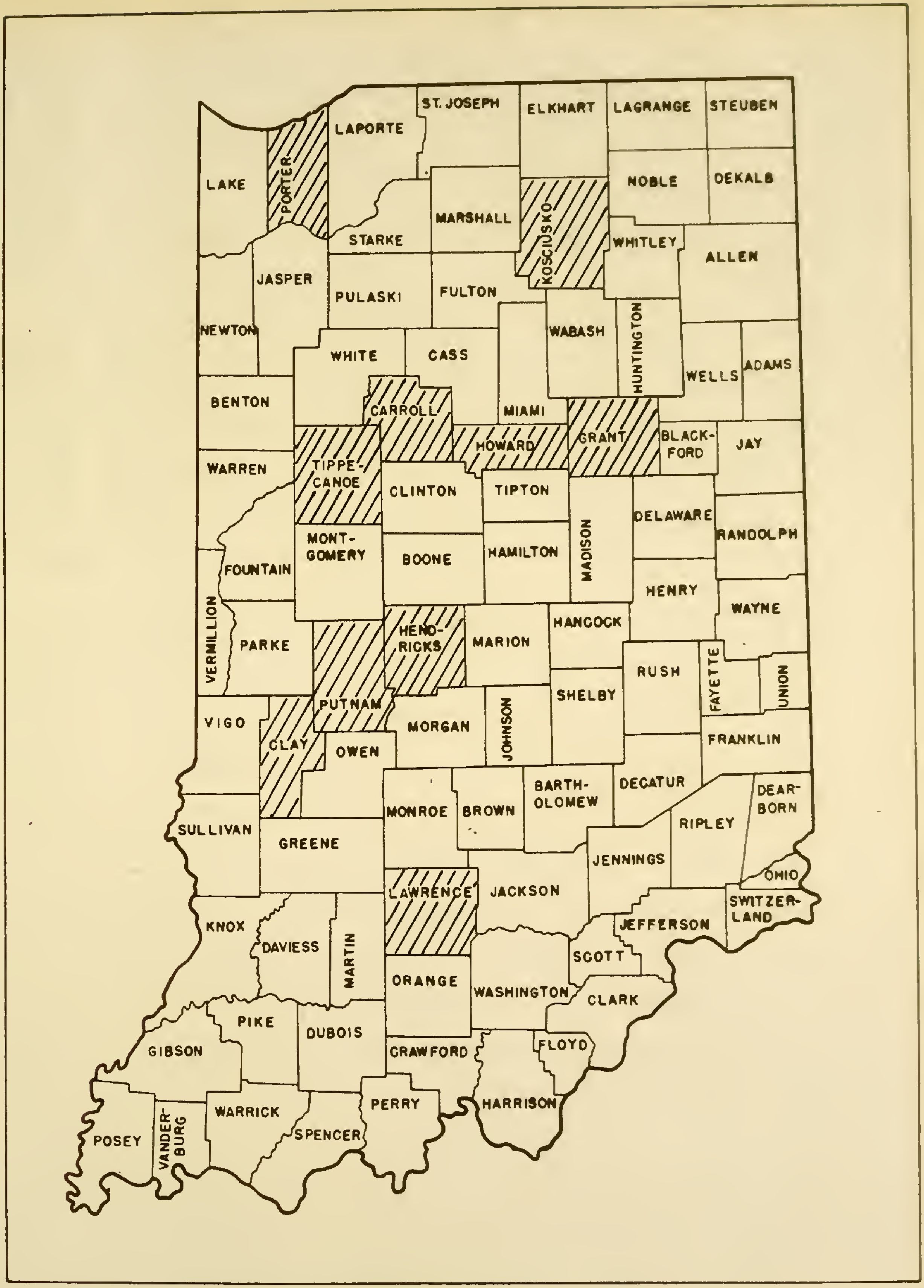
Analysis of Accident Reports

The original plan was to obtain the total number of accidents and the number of these accidents in which skidding was involved from the punch cards via mechanical sorting. It would have then been necessary to resort to the accident reports for specific accident locations for only those lengths of road that had a high significant skidding rate. However, the reliability of part of the data was questioned and it was deemed advisable to obtain all of the information directly from the accident reports by manual tabulation.

This change necessitates a reduction in the number of counties originally planned for study because of the time consumed by the manual operations. Consequently, the study was restricted to the ten counties indicated in Figure 2. These counties were selected at random from the seventeen counties originally planned for study and in which a pilot study on a few roads was conducted. These seventeen counties were selected at random from those in which highway sections were tested for skid characteristics in the performance of a previous Joint Highway Research Project investigation (6).

The total number of accidents occurring on a road length in 1958, and the number of these accidents in which one or more vehicles skidded, were tabulated by road surface condition. Skidding was recorded as occurring and/or after braking. However, if skidding occurred both before and after braking, a special note was made so that the total number of accidents in which skidding was involved could be determined. The location was also recorded for the purpose of identification of accident clusters. The date on which each accident occurred was also noted for possible future reference. The same information was collected on the basis of the number of vehicles involved in the accidents in the event this information would be of value later in the study.

In those cases where the accident was investigated by a law officer, the investigator's report was used as the source of data. When the accident was not investigated, the operator's report was utilized. In the latter case when there were different reports of the same accident, they were checked against each other and if a difference in information was reported, the most complete report was assumed to be the most



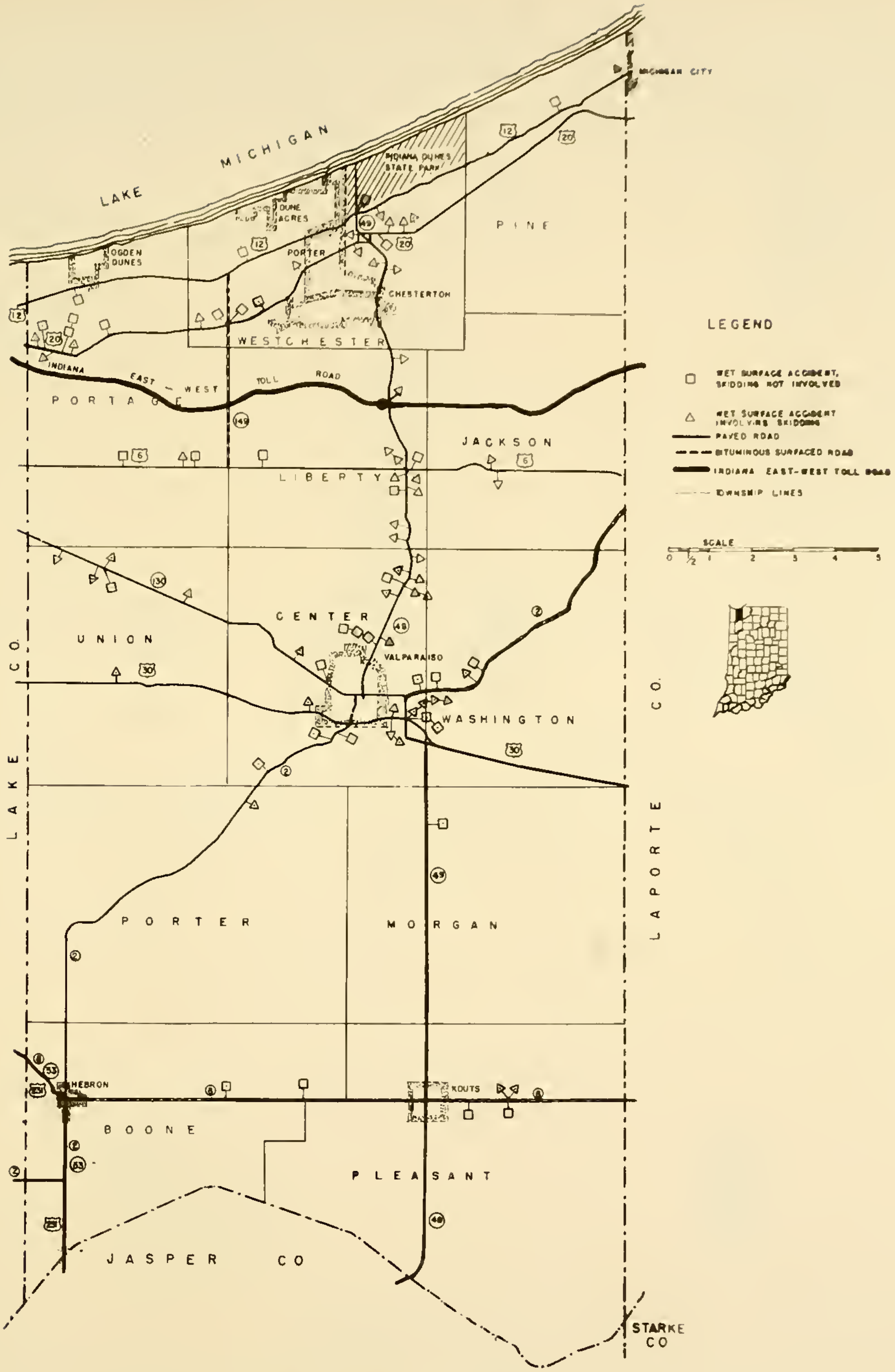
LOCATION OF COUNTIES STUDIED

FIGURE 2

reliable. In a few instances, an accident could not be used for analysis since there was no investigator's report and the operator's report(s) was so incomplete as to be worthless. At this point it might be mentioned that, without exception, the reports completed by members of the Indiana State Police were extremely complete.

The total number of accidents, and the number of these accidents in which skidding occurred before or after braking, was tabulated for the several road lengths. Where a highway follows the boundary between two townships, the accidents reported as occurring in each of these townships were added and analyzed as a single road length since only one roadway was involved.

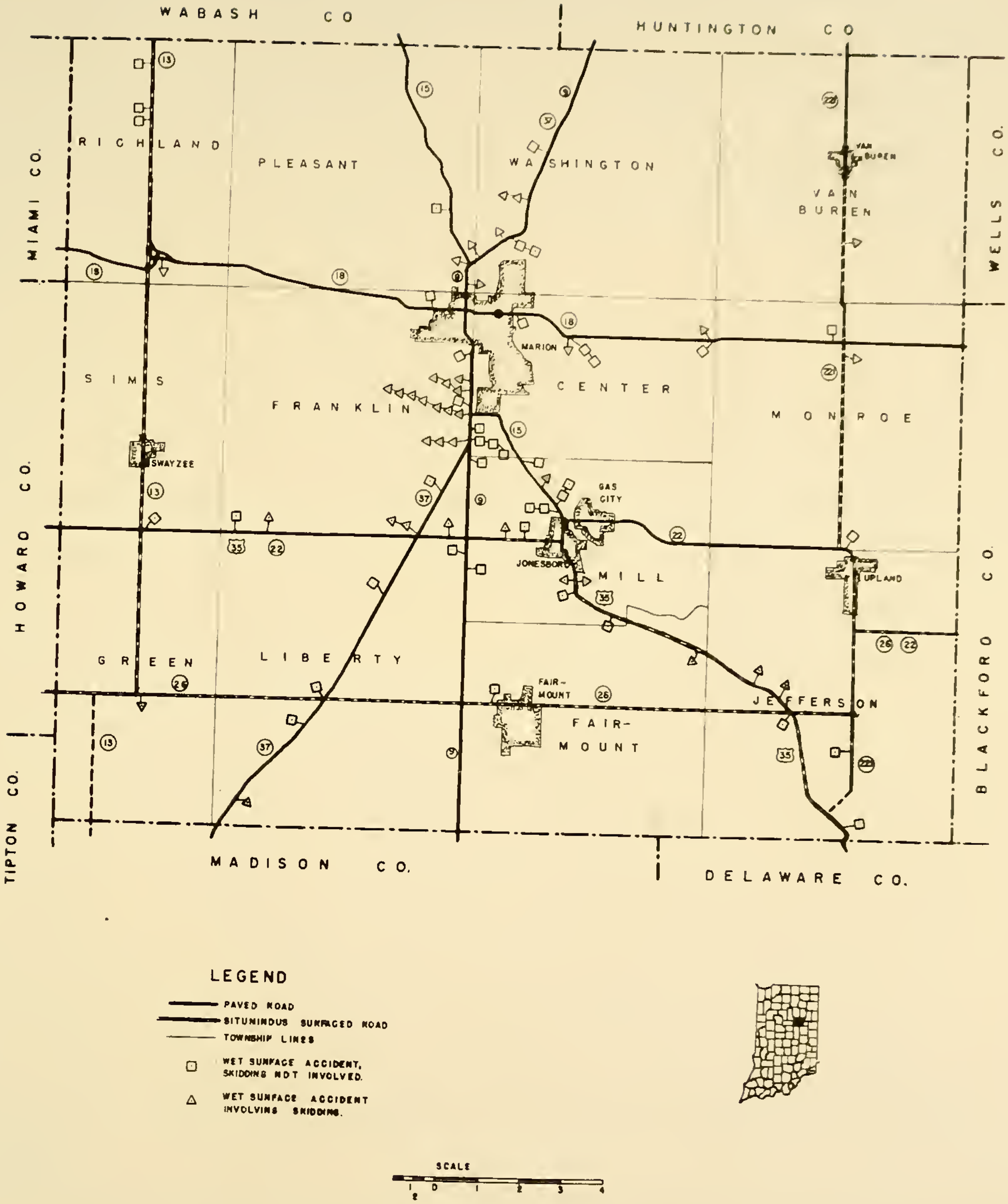
According to the present accident records procedure of the Indiana State Police, all accidents that occur on a single roadway which is traversed by two or more marked routes should be reported, coded, and filed under the lowest numbered U. S. marked route or under the lowest numbered State marked route when there is not a U. S. marked route. However, in some cases accidents were not filed under the prescribed lowest numbered route. Therefore, where two or more routes occupied the same roadway throughout a township, the number of accidents filed under each route were added and analyzed for a single road length. A considerably different problem presented itself where the roadway is common throughout only a portion of the length through a township. For this reason, as well as to aid in the identification of accident clusters, all wet surface accidents were plotted on county accident location maps as shown in Figures 3 and 4. Visual inspection of the ten maps then revealed the number of wet surface accidents and the number of



PORTER COUNTY
INDIANA

TYPICAL COUNTY ACCIDENT LOCATION MAP

FIGURE 3



GRANT COUNTY
INDIANA

TYPICAL COUNTY ACCIDENT LOCATION MAP

FIGURE 4

these accidents in which skidding occurred for all the road lengths, including the above mentioned problem locations. The SSR for each length of road was then easily determined by the use of Table 2. A summary of these results, by county, is presented in Table 3. Table 4 indicates the route, township, and county of the road lengths comprising the groups having an SSR of twenty and over.

The utilization of these accident location maps also permitted the determination of the accident clusters with considerable ease. Figures 3 and 4 are rather typical of the grouping tendency of wet surface accidents which involve skidding. The total number of accidents comprising a cluster and the number of these accidents which involved skidding is also apparent. With this information available the SSR of each cluster was determined by the use of Table 2. A list of those clusters having an SSR of twenty or more is given in Table 5.

In the process of plotting the accidents on the location maps, some problems involving the referencing of accident locations were encountered. A few cases were found where the mileage between two easily located places on a highway, such as the city limits of a town and the intersection of two highways, was reported inaccurately. This discrepancy was as much as one mile in a distance of three miles and might be considered a basis for questioning the accuracy of other reported distances.

In some cases where the accident location was referenced to development along the right of way, it was difficult, or impossible, to determine the exact location of the accident. These difficulties suggest the desirability of an established reference system along the highway.

TABLE 3

DISTRIBUTION OF THE SSR BY ROAD LENGTH (WET SURFACE CONDITION) FOR THE TEN COUNTIES STUDIED[**]

County	Significant Skidding Rate[***]										Total
	50 and over	45	40	35	30	25	20	11-15	1-10	NS[*]	0	
Carroll		1			1	1	2	1	1	4	12	23
Clay					1			1	1	8	10	21
Grant			1					5	5	9	19	39
Hendricks	2			1	3		2	3	3	5	10	29
Howard				1			1	2		4	12	20
Kosciusko		1			1		1	4	2	4	16	29
Lawrence	1						3	3	1	4	8	20

[*] Not significant

[**] Does not include those lengths of road that were resurfaced or reconstructed between December 31, 1957 and January 1, 1959.

[***] Each of the column headings listed constitutes a stratum for the field skid correlation investigation.

TABLE 3 (Continued)

	Significant Skidding Rate										
County	50 and over	45	40	35	30	25	20	11-15	1-10	NS	0	Total
Porter	1				4	1		3	2	7	15	33
Putnam	4	2	1	1			1	2		2	8	21
Tippecanoe	1		1	2	1	2		5	2	5	13	32
Total	9	4	3	5	11	4	10	29	17	52	123	267

TABLE 4

LIST OF ROAD LENGTHS WHICH HAVE A SIGNIFICANT SKIDDING RATE OF THAT INDICATED OR HIGHER*

Route	Township	County
SSR of at least 50%		
US 40	Liberty	Hendricks
US 40	Washington	Hendricks
US 50	Shawswick	Lawrence
SR 49	Liberty	Porter
US 40	Warren	Putnam
US 40	Washington	Putnam
US 231 (also SR 43)	Monroe	Putnam
US 231 (also SR 43)	Warren	Putnam
US 52 By-Pass	Fairfield	Tippecanoe
SSR of at least 45%		
SR 18	Monroe	Carroll
SR 15	Wayne	Kosciusko
US 231 (also SR 43)	Greencastle	Putnam
US 40	Marion	Putnam
SSR of at least 40%		
SR 9	Center-Franklin	Grant
US 231 (also SR 43)	Franklin	Putnam
SR 25	Washington	Tippecanoe

TABLE 4 (Continued)

Route	Township	County
SSR of at least 35%		
US 36	Washington	Hendricks
US 35 (also SR 22)	Howard-Taylor	Howard
SR 240	Marion	Putnam
SR 28	Jackson	Tippecanoe
SR 28	Lauramie	Tippecanoe
SSR of at least 30%		
SR 29	Burlington	Carroll
US 40	Posey	Clay
US 36	Center	Hendricks
US 40	Franklin	Hendricks
SR 67	Guilford	Hendricks
SR 15	Van Buren	Kosciusko
US 20	Westchester	Porter
US 30	Center	Porter
US 36	Center	Hendricks
SR 49	Washington-Center	Porter
SR 38	Shefield	Tippecanoe
SSR of at least 25%		
SR 18	Carrollton	Carroll
SR 130	Union	Porter
SR 26	Fairfield	Tippecanoe
US 52	Wabash	Tippecanoe

TABLE 4 (Continued)

Route	Township	County
SSR of at least 20%		
US 421	Deer Creek	Carroll
US 421	Tippecanoe	Carroll
US 40	Guilford	Hendricks
US 136	Lincoln	Hendricks
US 31	Center	Howard
US 30	Washington	Kosciusko
SR 37	Marshall	Lawrence
US 50	Marion	Lawrence
US 50	Spice Valley	Lawrence
US 231 (also SR 43)	Cloverdale	Putnam

TABLE 5

LOCATION OF ACCIDENT CLUSTERS WHICH HAVE A SIGNIFICANT SKIDDING RATE OF AT LEAST THAT INDICATED

Route	Township	County	Location
SSR of at least 50%			
SR 9	Center	Grant	1000 ft. north of junction with SR 15 (38th St.) to 300 ft. south
US 36	Washington	Hendricks	Danville to 2 mile east of Avon
US 40	Liberty	Hendricks	2 1/4 mile west of Plainfield to 3 miles west of Belleville
US 50 (also SR 37)	Shawswick	Lawrence	White River Bridge to 1.2 miles north
US 40	Warren	Putnam	1/4 mile west of Putnamville to the top of hill east of Deer Creek Bridge
US 231 (also SR 43)	Warren	Putnam	Junction US 40 to 1/4 mile south of junction US 40
SR 25	Washington	Tippecanoe	1000' west of junction SR 225 to Buck Creek Bridge
US 52 By-Pass	Fairfield	Tippecanoe	500' south to 300' north of Union Street
US 52 By-Pass	Fairfield	Tippecanoe	200' north of Kossuth Street to National Homes Plant Entrance
SSR of at least 45%			
SR 18	Monroe	Carroll	3.4 to 1 1/4 mile east of Flora

TABLE 5 (Continued)

Route	Township	County	Location
US 40	Guilford-Washington	Hendricks	1 1/4 east of Plainfield to Hendricks-Marion County line
SR 49	Center	Porter	1 1/2 mile to 3 1/2 mile north of Valparaiso city limits
SR 25	Washington	Tippecanoe	2 miles south to 1 3/4 mile north of Americus
SSR of at least 40%			
None			
SSR of at least 35%			
US 421	Tippecanoe	Carroll	Junction with SR 18 to 1 1/2 miles north
US 40	Franklin	Hendricks	1/4 mile west of Stilesville to Stilesville city limits
SSR of at least 30%			
SR 18	Carrollton	Carroll	From south-west branch Little Deer Creek Bridge to 1 mile east
SR 67	Guilford	Hendricks	From Morgan-Hendricks county line to Marion-Hendricks county line
US 20	Westchester	Porter	Junction of SR 49 to 2 miles east
US 40	Marion	Putnam	500 ft. west to 1 mile east of Mt. Meridian

TABLE 5 (Continued)

Route	Township	County	Location
SSR of at least 25%			
US 30	Center	Porter	300 ft. west of west junction SR 40 to 1000 ft. east of east junction of SR 49
SSR of at least 20%			
SR 267	Washington-Lincoln	Hendricks	Junction US 136 in Avon to 2 1/2 miles north
SR 49	Liberty	Porter	600 ft. north to 1/4 mile south of junction with US 6
SR 26	Fairfield	Tippecanoe	Junction with US 52 By-Pass to 1.1 mile east

An absolute system, such as mile-posts established both in the field and on highway maps, would greatly facilitate accident reporting and analysis if effectively used to report accident locations. It should remove much of the doubt as to the exact location of many accidents and therefore be of considerable help in determining which accidents actually constitute a group. This would then aid in the determination of the distance that should be "de-slicked" and where this operation should begin and end.

FIELD SKID INVESTIGATION

Scope

This phase of the study was designed to collect field measurement data of the slipperiness of pavement surfaces. These data were then used to determine the extent of the correlation existing between the SSR and the slipperiness of the surface. These field measurements were conducted with a special test vehicle employing the stopping distance method. Because the testing of all 267 road lengths in the ten counties was prohibitive for reasons of time and expense, the tests were conducted on only a few road lengths. These sample locations were selected by statistical techniques so as to insure that the data obtained would be representative of all the road lengths.

Test Sites, Equipment, and Procedure

Before picking the sample that was field tested, it was necessary to determine which lengths of roadway had been resurfaced or reconstructed after December 31, 1957. This was done so as to retain only those lengths of roadway which had the same pavement surface for all of the accident period, and which still had that same surface at the time of field testing. A list of these lengths of highway was then prepared with the several lengths of highway arranged in decreasing magnitude of the significant skidding rate.

The locations at which the field skid tests were performed were chosen from this listing using a stratified random sample and a table of random numbers (7). The strata used are indicated in Table 3. The stratified sample was used so as to insure that each of the various levels of the significant skidding rate would be represented. Had simply a random sample been selected, the low frequency but high value significant skidding rates might not have been represented in sufficient numbers to obtain correlation data for the entire range of the significant skidding rate. Except for the highest, two locations were chosen from each stratum. Three were chosen from the fifty percent and over stratum because more variability in the significant skidding rate was present in this case. The increased variability in this stratum was due to the fact that some lengths of road had a proportion of skidding accidents in excess of that necessary for a significant skidding rate of fifty percent. Calculations were not made for values above fifty percent for two reasons; the first being that very few lengths of road exceeded this significant skidding rate by a sizable margin. Secondly, a significant skidding rate of fifty percent is dangerously high and the route is in critical need of attention.

For practical reasons in making arrangements with the various districts of the highway department, no skid tests were performed in those districts in which less than three locations were to be tested. Only two site changes were made for this reason. In both cases, the location substituted was the next one selected on the basis of the table of random numbers.

The skid tests were conducted with the State Highway Department

of Indiana skid vehicle. This vehicle has an electrically-activated, vacuum-braking unit, and thus eliminates driver variation in application of the brakes. It is also equipped with a fifth-wheel so that at the instant the braking system is activated, a special speedometer records the speed to a tenth of a mile per hour and a special odometer measures the distance required to stop to tenths of a foot. Complete details of the vehicle and its use are reported by Michael and Grunau (6).

It was attempted to perform all tests from a speed of exactly 30 miles per hour on a thoroughly wet surface. For those tests in which the speed was slightly different than desired, the stopping distance was corrected according to the following formula:

$$\text{Corrected Stopping Distance} = \text{Stopping Distance Measured}\left(\frac{30}{V}\right)^2$$

where V is the speed at which the test vehicle was actually travelling when the brakes were applied.

If the actual speed varied more than one mph from the desired speed of 30 mph, that particular run was aborted at some point in the test and another run was performed.

To insure that the surface was thoroughly wet, two passes were made with the distributor truck immediately before the first test and one pass was made before each succeeding test. Two satisfactory tests were made in each direction at each location. In general, only two trials were necessary in each direction. However, at some locations, especially the more slippery ones, more trials were necessary due to

the vehicle skidding off the road or skidding sideways. In these cases the faulty trials were disregarded. Tire pressure was maintained at thirty psi and was checked three times per day (before beginning the day's tests, at noon, and upon completion of the day's testing).

On those lengths of highway where there was a grouping of wet-surface skidding accidents, the skid tests were made at or as close as possible to the location of the accident cluster having the highest SSR. The skid tests were conducted at a location chosen at random on those lengths of highway on which no accident cluster was present. All skid test locations were on tangent and, if possible, level sections of highway. Tangent sections were selected in order to obtain sufficient sight distance so as to allow approaching vehicles to stop comfortably and safely, as well as to provide a straight path for the test vehicle to slide during the test. Level sites were desired to eliminate the effect of grade; however, it was necessary to conduct the tests on two lengths of highway on slight grades. In these two cases it was assumed that the effect of the down grade in one direction would be balanced, when the average skid distance for both directions was computed, by the effect of the up grade in the two tests performed in the opposite direction. Both of the sites were on two lane highways.

All tests were conducted with the test vehicle traveling in the direction of traffic. For safety reasons, traffic was halted in both directions on two lane highways and in the direction the test vehicle was traveling on divided highways while the actual skid tests were being conducted. Traffic was maintained to the greatest possible extent while the surface was being wetted.

Upon substantial completion of the testing program, it was discovered that maintenance operations had changed the surface characteristics of one of the locations in the thirty-five percent stratum. It was decided to drop this stratum rather than to use it with only one value. This reduced the number of sites from twenty-three to twenty-one.

The results of the skid test on the twenty-one locations retained in the sample are presented in Table 6. The values shown in the average distance to stop column are the averages of the four tests conducted at each location. It is this average value that was used in the correlation analysis.

Rou
US 1
SR 6
US 5
SR 3
US 5
SR 2
US 2
SR 2
US 3
US 4
US 4
SR 2
US 3
SR 4

TABLE 6

SUMMARY OF SKID TESTS ON SAMPLE ROAD LENGTHS

Location				Number of Feet Required to Stop from 30 MPH		
Route	County	Township	Site Description	Average	Minimum	Maximum
US 12	Porter	Portage	0.1 mile east of Ogden Dunes	49.8	49.0	50.4
SR 60	Lawrence	Marion	1.6 mile South of Spring Mill Park Entrance	55.6	55.2[b]	56.1
US 52	Tippecanoe	Sheffield	1/2 mile northwest of County Road 75	56.7		
			Northbound roadway	59.0	58.5	59.5
			Southbound roadway	54.5	52.7	56.1
SR 37	Grant	Liberty	800' north of junction with SR 26	64.5	63.0[b]	67.8
US 50	Lawrence	Marion	0.4 mile west of junction with SR 37	65.8	64.1	70.0
SR 267	Hendricks	Washington	3.3 miles south of junction with US 136	72.1	68.4[b]	73.5
US 20	Porter	Westchester	1.5 miles east of SR 49 interchange	75.1	69.0	80.5
SR 25	Tippecanoe	Washington	3.4 miles north of junction with US 52 By-Pass	77.6	76.3	79.0
US 35	Grant	Jefferson	0.3 mile north of junction with SR 26	77.8	76.8[b]	78.6
US 40	Putnam	Marion	3.7 miles east of Mt. Meridan	78.5		
			Eastbound roadway	65.4	63.4	67.4
			Westbound roadway	91.6	89.2	94.0
US 40	Hendricks	Franklin	0.5 miles east of Stilesville	78.8		
			Eastbound roadway	70.2	68.6	71.7
			Westbound roadway	86.4	85.6	87.2
SR 26	Tippecanoe	Fairfield	0.3 miles east of junction with US 52 By-Pass	80.2	76.5	88.6
US 35	Grant	Mill	1 1/4 mile south of Jonesboro	84.5	77.5	89.0
SR 49	Porter	Westchester	1/2 mile south of junction with US 20	85.1	81.7	89.2

Rou
SR 1
SR 4
US 4
SR 9
US 2
US 2
US 5 By-P

TABLE 6 (Continued)

Location				Number of Feet Required to Stop from 30 MPH		
Route	County	Township	Site Description	Average	Minimum	Maximum
SR 130	Porter	Union	0.1 mile east of Wheeler	85.2	83.6	87.3
SR 49	Porter	Liberty	0.2 miles north of junction with US 6	90.7	72.2[a]	108.9
US 40	Putnam	Warren	600' west of Deer Creek Bridge	91.5	90.8	92.3
SR 9	Grant	Center	500' north of junction with SR 15 (38th street)	97.8	92.9[b]	102.5
US 231	Putnam	Cloverdale	600' north of junction with SR 343	98.2	85.2[a]	111.4
US 231	Putnam	Greencastle	1/2 mile south of Eel River Bridge	103.6	103.1	106.2
US 52 By-Pass	Tippecanoe	Fairfield	Midway between Union and South Streets	105.8	103.8	107.0

[a] Test site on slight grade.

[b] Minimum and maximum stopping distances occurred in same traffic lane.

SPEED AND VOLUME INVESTIGATION

Scope

Upon the completion of the field skid testing, the data were plotted as scatter diagrams. Visual inspection of these diagrams and knowledge of the traffic conditions at the various locations indicated that speed and volumes might be two additional factors which affected the SSR. This phase of the study was then introduced to determine if a relationship does exist between the SSR and speeds and/or volumes. With this purpose in mind, speed and volume data were obtained on all of the twenty-one highways upon which field skid tests were conducted.

Speed Sites, Equipment, and Procedures

The collection of speed data was initially begun using an electric meter employing two rubber road tubes spaced exactly eleven feet apart. However, it became apparent that spot speeds may not satisfactorily represent the speed situation over even a relatively short distance. Since it appeared desirable to have the speed data represent, as nearly as possible, the speed for a particular route throughout an individual township, it was decided to use the mean speed of vehicles over a distance. These mean speeds, hereafter referred to as mean over-all speeds, were obtained by the license plate matching method. The time, to the nearest second, and the license plate number were recorded when a vehicle

entered and left a measured distance. Synchronized stopwatches reading to 1/2 of a second were used to record the time. After collecting the necessary data at a location, the two watches were checked for synchronization; in all cases their difference in time was less than approximately 3/4 of a second.

The distance through which the vehicles passed was measured by means of a calibrated measuring wheel. Wherever possible, a three mile course was measured. However, in some cases it was necessary to use a shorter distance in order to remain within the desired township. At one location it was necessary to employ a distance of one mile; at least 1 1/2 miles were available at the remaining locations. Except for SR 9, Center Township, Grant County and US 52 By-Pass, Fairfield Township, Tippecanoe County, these travel-time data were obtained on rural highways. For the two exceptions just mentioned, the data were obtained in developed area adjacent to the city limits of Marion and Lafayette respectively.

Reconstruction of the shoulders on the eastbound roadway of US 52, Sheffield Township, Tippecanoe County, was in progress at the time. However, it is felt that this did not materially affect the results since work was not actually being conducted at the time and there was no significant difference in the average speeds of the eastbound and westbound roadways.

A single distance was used to determine the mean speed on US 35 through both Mill and Jefferson townships as they are neighboring townships where the highway has similar geometric design and surface characteristics. The distance through which the vehicles were timed included

both skid test sites on this highway in these two townships.

As previously stated, the license plate method was employed to obtain the travel time for each vehicle. The calculation was performed by determining a mean travel-time for each course and this in turn was converted to the mean over-all speed. The speeds indicated are, therefore, space mean speeds which may be expressed as:

$$\text{Spaced mean speed} \quad \frac{\text{distance}}{\Sigma t/n}$$

where Σt is the sum of the individual travel times, n is the number of vehicles for which the travel time was obtained and the distance is the length of the measured course.

Sufficient license plate matchings were made to determine the mean over-all speed with an error not to exceed five percent with ninety-five percent confidence (8).

The speed data were collected during weather conditions that varied from warm and clear to cold and cloudy. Since the study is concerned with skidding on wet surfaces, the question might arise as to the value of the data obtained. Previous investigations (8) have found that although speeds decrease when a rain-fall first begins, the drivers soon return to their former speed, providing the intensity of rain-fall is not sufficient to cause a reduction in visability. Therefore, little, if any, appreciable error should be involved due to the collection of the speed data under dry rather than wet surface conditions.

The results of the speed study are shown in Table 1 of the Appendix.

Traffic Volumes

It is reasonable to expect that some relationship might exist between the significant skidding rate and the vehicular volume. The average annual daily traffic (ADT) for the twenty-one sample road lengths was determined from the 1958 Indiana Traffic Flow Map. This information is also shown in Table 1 of the Appendix.

DISCUSSION OF RESULTS

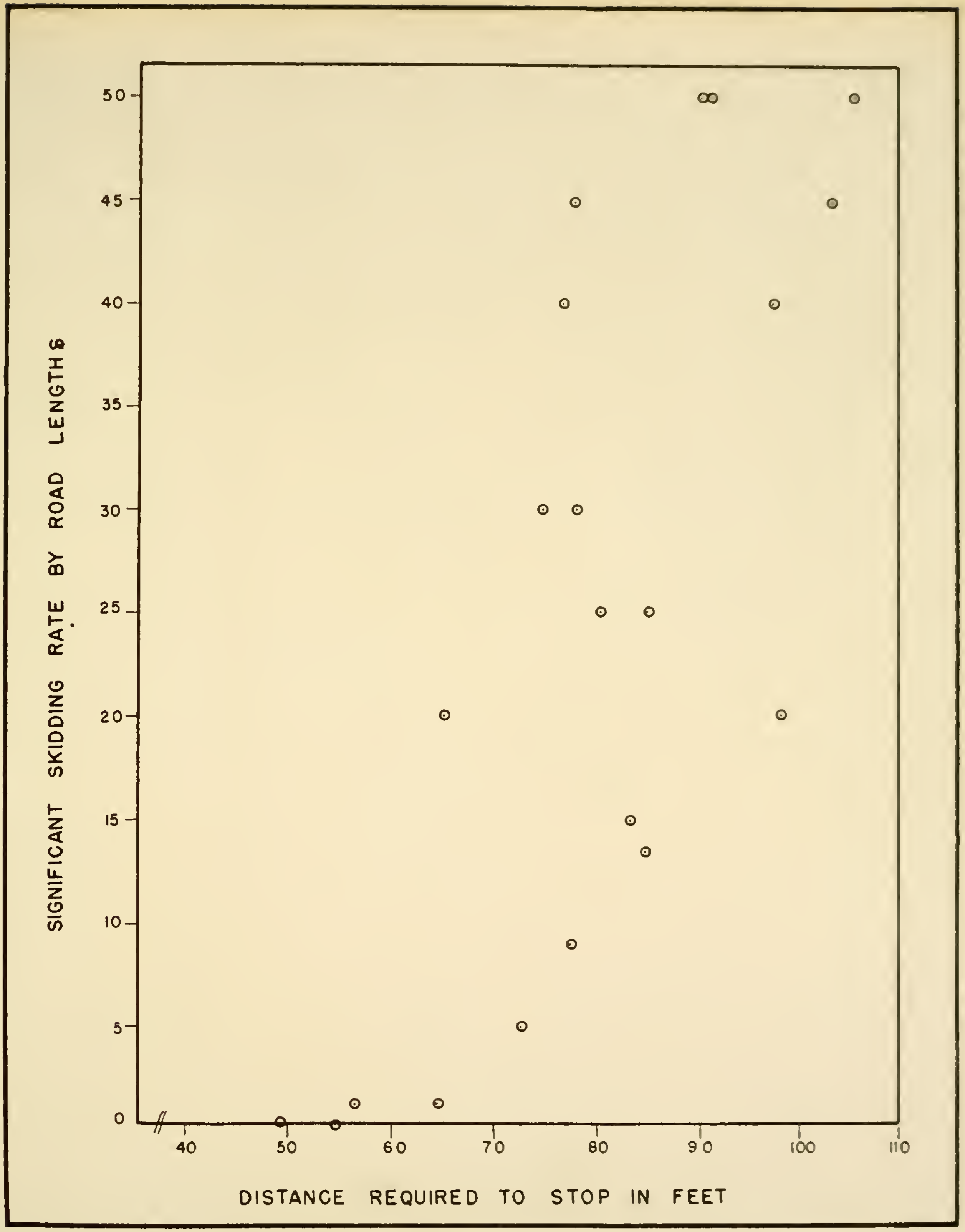
Factors Affecting the SSR

The inter-relationships between the SSR, the slipperiness of the surface, the mean over-all speed, and the ADT necessitate the discussion of the regression-correlation analysis in a single section. Analysis was conducted using both the road length and the accident cluster as a unit of study. Calculations for the values here-in discussed are presented in the appendix.

Scatter diagrams were plotted with the significant skidding rate (SSR) as the ordinate and the distance required to stop, mean over-all speed, or average annual daily traffic as the abscissa. For the road lengths, these diagrams are shown in Figures 5, 6, and 7 respectively; for the accident clusters, in Figures 8, 9, and 10.

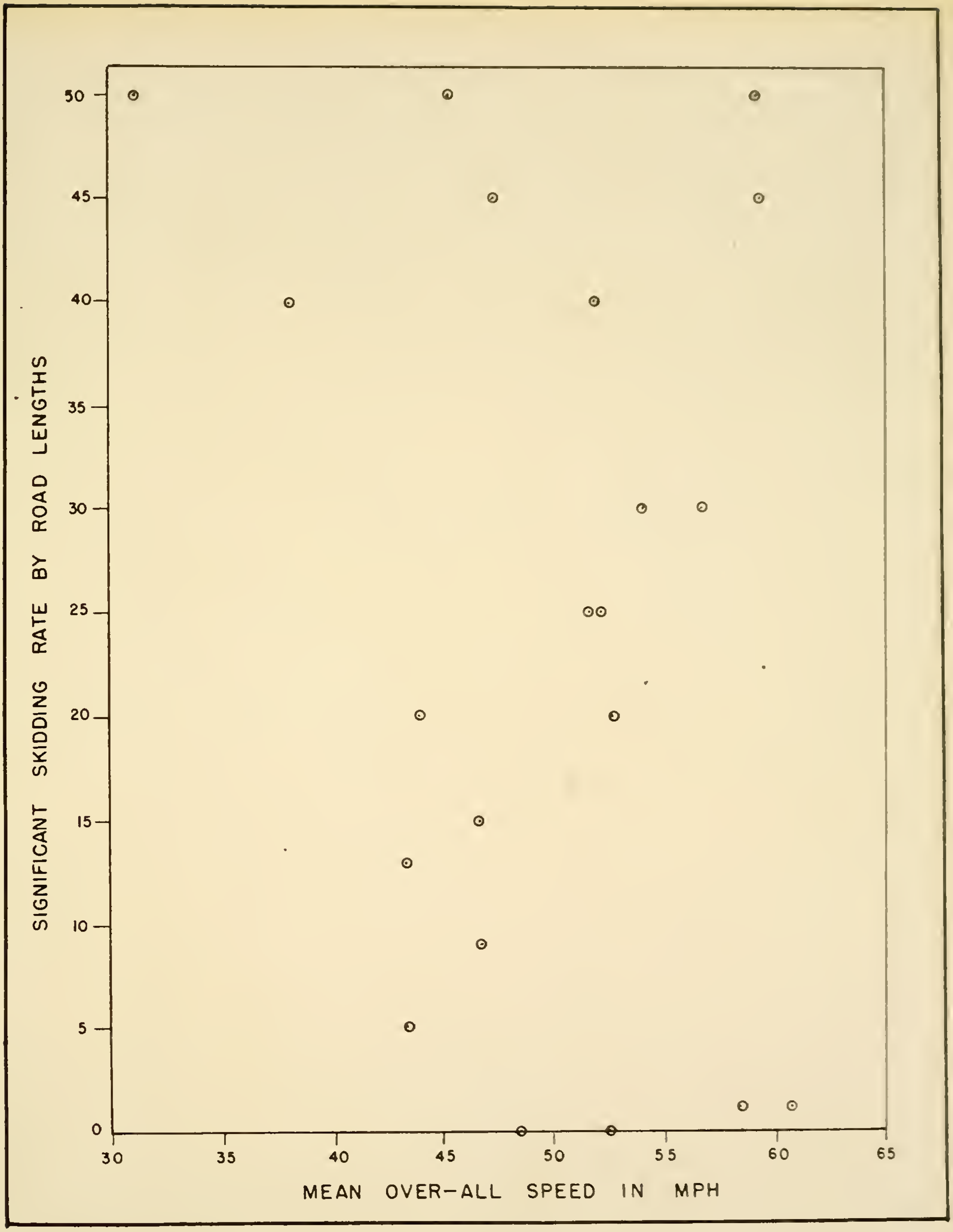
The simple correlation coefficients (r_{iy}) were then calculated for the various possible combinations of factors. The pertinent combinations, the numerical values of these coefficients, and the results of the tests of significance are summarized in Table 7.

In the examination of the simple correlation coefficients, it must be remembered that they are a measure of the dependence between the two factors being considered and may include influence of other variables.



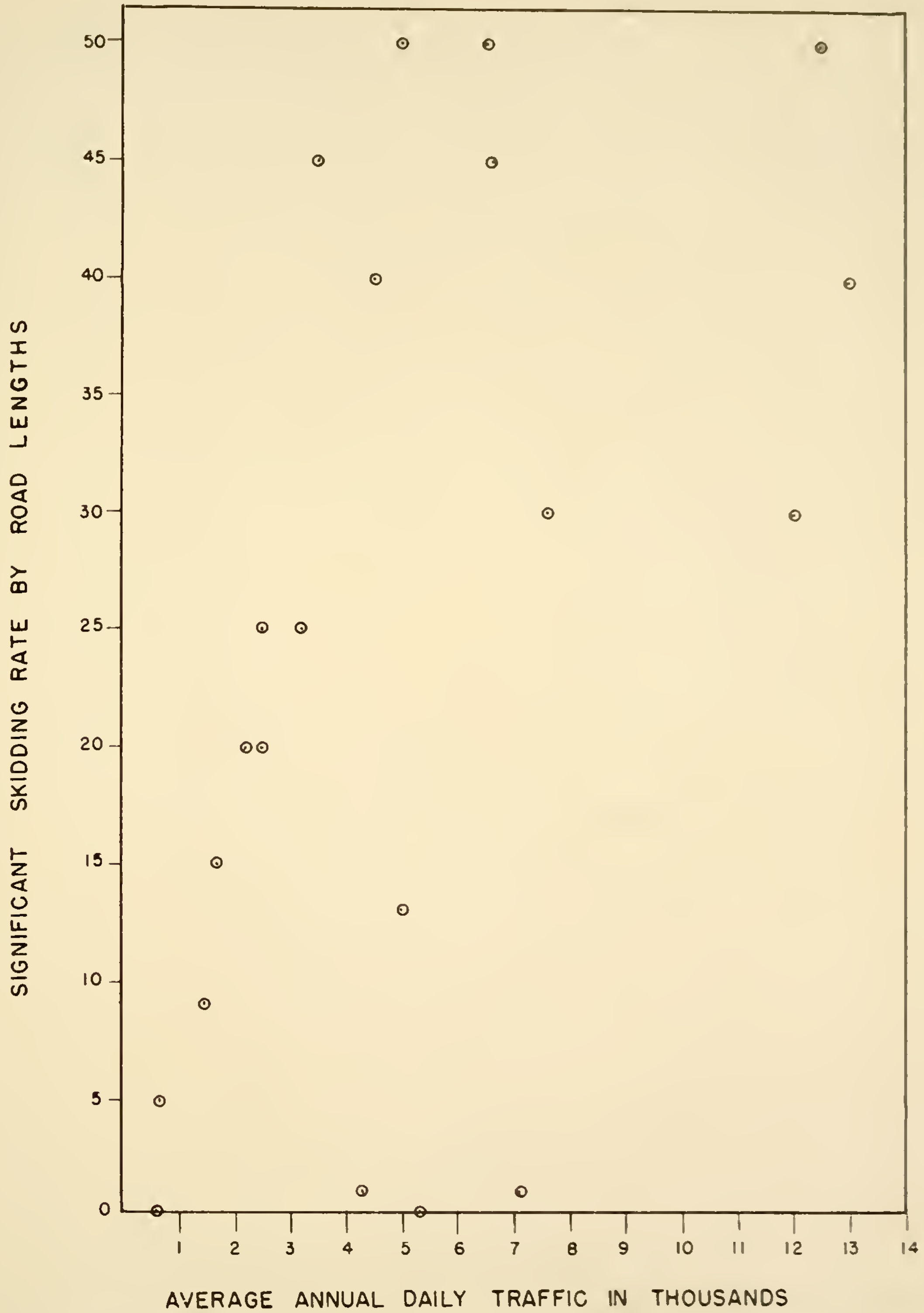
SCATTER DIAGRAM OF THE DISTANCE REQUIRED TO STOP AND THE SIGNIFICANT SKIDDING RATE BY ROAD LENGTH

FIGURE 5



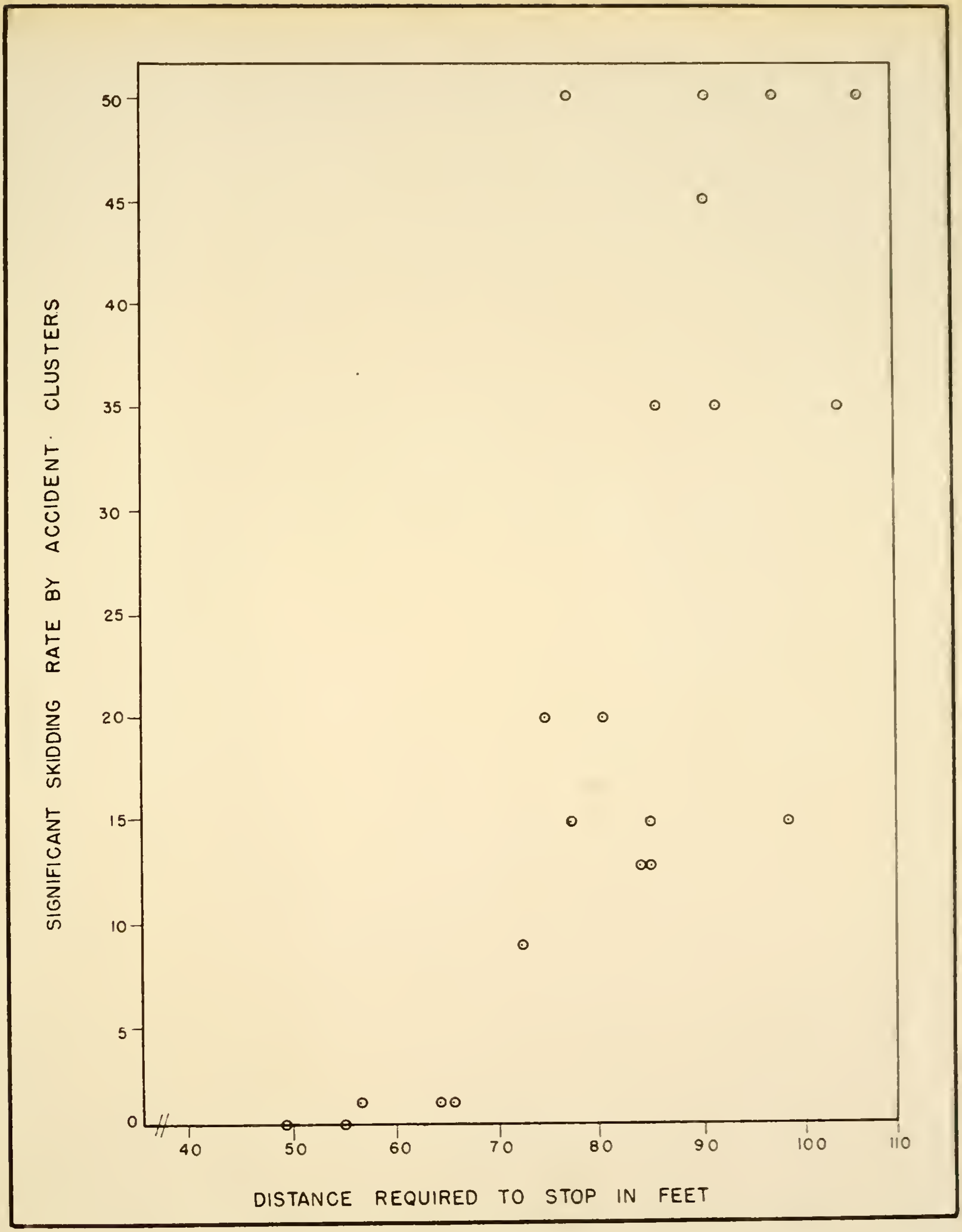
SCATTER DIAGRAM OF THE MEAN OVER-ALL SPEED AND THE SIGNIFICANT SKIDDING RATE BY ROAD LENGTHS

FIGURE 6



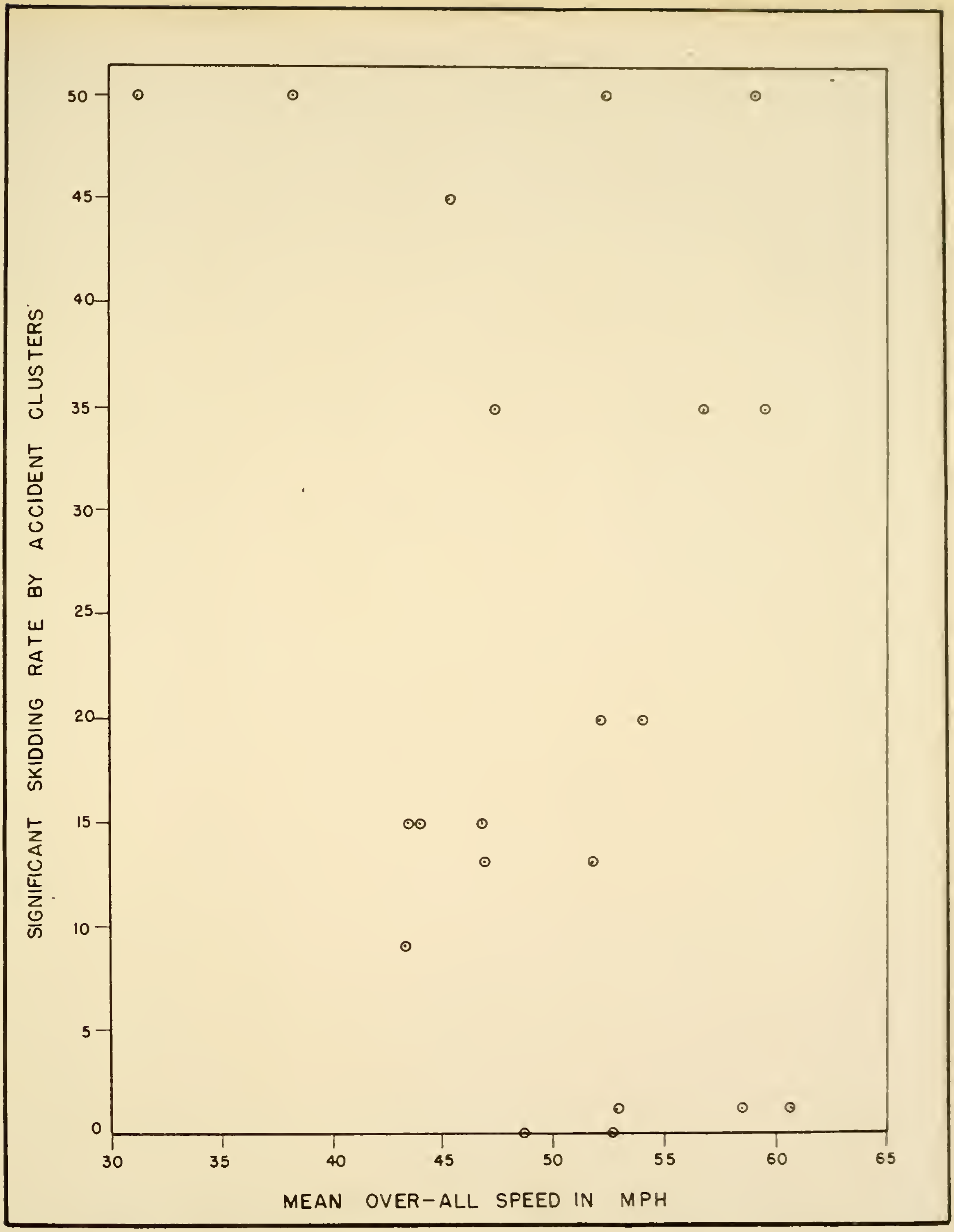
SCATTER DIAGRAM OF THE AVERAGE ANNUAL DAILY TRAFFIC AND THE SIGNIFICANT SKIDDING RATE BY ROAD LENGTHS

FIGURE 7



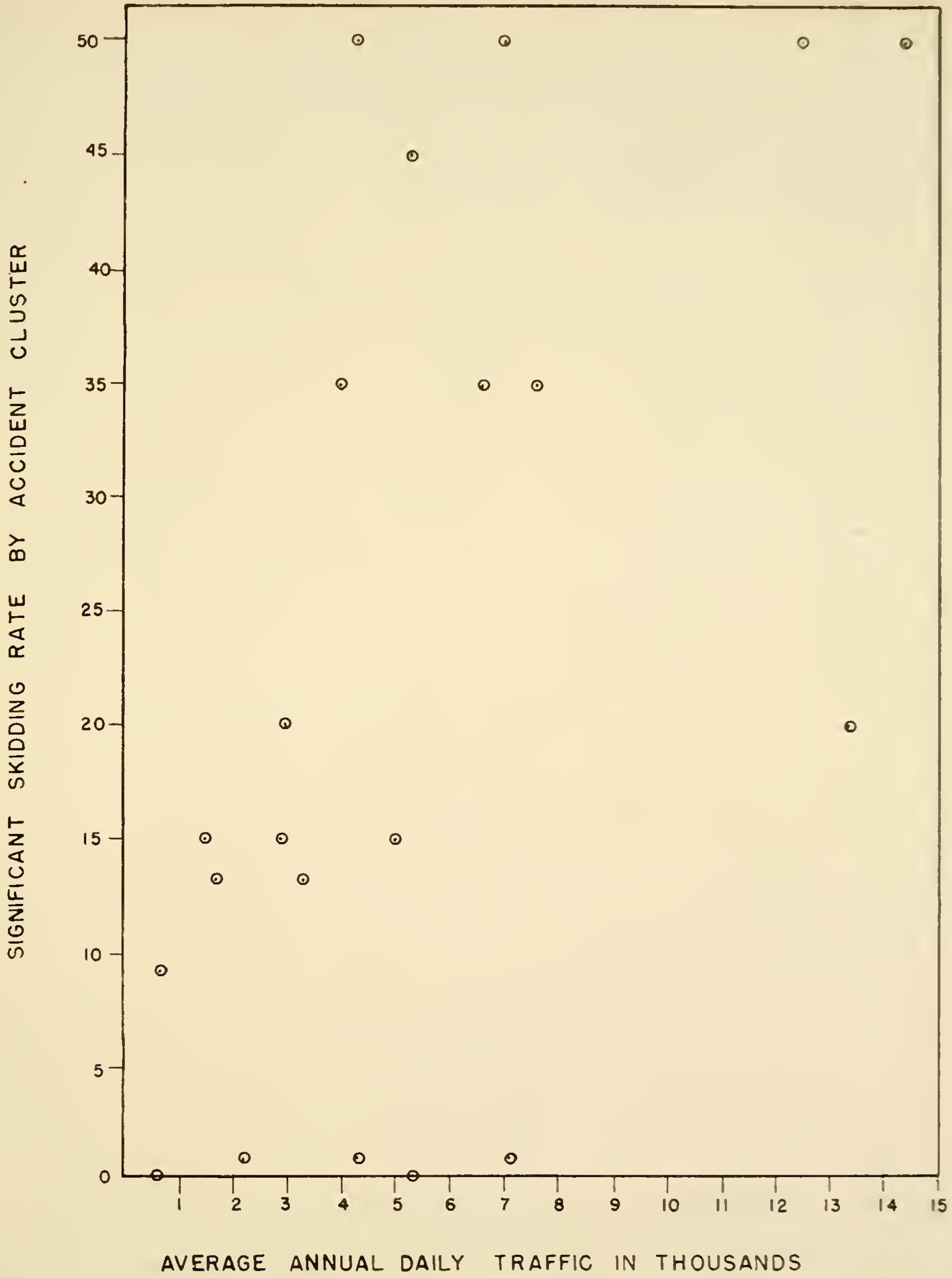
SCATTER DIAGRAM OF THE DISTANCE REQUIRED TO STOP AND THE SIGNIFICANT SKIDDING RATE BY ACCIDENT CLUSTER

FIGURE 8



SCATTER DIAGRAM OF THE MEAN OVER-ALL SPEEDS AND THE SIGNIFICANT SKIDDING RATE BY ACCIDENT CLUSTER

FIGURE 9



SCATTER DIAGRAM OF THE AVERAGE ANNUAL DAILY TRAFFIC AND THE SIGNIFICANT SKIDDING RATE BY ACCIDENT CLUSTER

FIGURE 10

TABLE 7

SUMMARY OF THE SIMPLE CORRELATION COEFFICIENTS

Factors Correlated For Road Lengths	Correlation Coefficient	Correlation Coefficient Squared	Significant*
SSR - slipperiness of surface	0.75	0.57	yes
SSR - mean over-all speed	-0.18	0.03	no
SSR - ADT	0.49	0.24	yes
For Accident Clusters			
SSR - slipperiness of surface	0.76	0.58	yes
SSR - mean over-all speed	-0.27	0.07	no
SSR - ADT	0.58	0.33	yes

* At the 0.050 level of significance.

The results indicate the presence of a highly significant positive correlation between the SSR and the slipperiness of the surface. Furthermore, approximately fifty-seven percent of the variation in the SSR can be explained by its dependence upon the slipperiness of the surface. Thus, the SSR is significantly related to the slipperiness of the roadway surface as measured by the vehicle stopping-distance method.

The absence of a significance in the correlation coefficient between the SSR and the mean over-all speed would indicate there is little, if any, relation between the two factors. However, visual inspection of Figure 6 appears to indicate the possibility of some relationship between speed and the SSR for those road lengths which have an SSR between five

and thirty. A correlation coefficient for the data within this range was calculated to 0.88; this value is very significant, at the 0.005 level. This, combined with the information presented in Figures 5 and 6, indicates that on moderately slippery surfaces the percent of accidents involving skidding when wet increases as the speed increases. Further comparison shows that, regardless of the speed, skidding occurs in an alarmingly high percentage of wet surface accidents when a wet surface provides low resistance to skidding. Examination of the lowest significant skidding rates indicates that a very low percent of wet surface accidents will involve skidding if the wet surface exhibits a uniformly high resistance to skidding; this is true regardless of the speeds at which the vehicles generally travel.

A positive correlation also exists between the SSR and the average annual daily traffic. Of the total variation in the SSR, twenty-four percent is explained by the dependence upon the ADT. The importance of this relationship is that the SSR inherently involves a consideration of the traffic volume. In general, a route which has a relatively slippery surface but carries a low volume of traffic will exhibit a lower value for its SSR than will a route which has a similar surface but a higher volume of traffic. Study of Figures 5 and 7 as well as the data represented there-in reveals that for surfaces having exceptionally good skidding characteristics the ADT has little, if any, affect upon the SSR. Further comparisons tend to indicate that roads having very low volumes would not be expected to show a high SSR even if the surface may be quite slippery. Therefore, separate study of the traffic volumes on the various facilities should not be necessary when determining the priority that a

particular section should be given for the application of corrective measures. Priority should be given to those locations which have the highest significant skidding rate.

The multiple correlation coefficient is, perhaps, of more value than the previously discussed coefficients because it measures the degree of linear association between all the factors under consideration. The value of this coefficient (R) was computed to be 0.85 and R^2 equals 0.73. Statistically this value is very highly significant. Thus, seventy-three percent of the total variation in the SSR is explained by its dependence upon the slipperiness of the surface, the mean over-all speed, and the ADT. The remaining twenty-seven percent must, therefore, be due to other factors affecting skidding.

Comparison of the simple and multiple correlation coefficients as well as the partial correlation coefficients (refer to the Appendix) reveals that the majority of the variation in the SSR is due to the slipperiness of the surface as measured by the distance required to stop. The above results were obtained when the SSR was determined on the basis of the road length, i. e., the total number of wet surface accidents occurring on a highway within a particular township and the number of these accidents which involved skidding were used to determine the SSR from Table 2.

Regression and correlation analysis was also conducted (Tables 6 and 7 of the Appendix) with the SSR calculated on the basis of the wet surface accident clusters. In this case, the total number of wet surface accidents comprising a cluster and the number of these accidents which involved skidding were used to determine the SSR. The cluster used was

that one in each road length which had the highest SSR and, as previously stated, determined the location at which the field skid tests were performed.

Each roadway of a four-lane divided highway was considered separately when identifying clusters on those facilities. This was done because the surfaces of the two roadways can have radically different skidding characteristics, especially if they have different pavement types. Also, corrective measures can be performed on one roadway without affecting the other; therefore, in the interest of economy, it is desirable to know if only one of the roadways is responsible for the skidding accidents.

The simple correlation coefficients computed with the analysis based on the accident cluster are of slightly larger magnitude and are somewhat more significant than those calculated for the road length analysis. The discussion previously presented applies equally to the coefficients for the accident cluster data shown in Table 7.

The multiple correlation coefficient for the accident cluster data was computed to be 0.86 and its square is 0.73. Thus, seventy-three percent of the total variation in the SSR for the accident clusters is explained by its dependence upon the slipperiness of the surface, mean over-all speed, and ADT.

Comparison of the corresponding simple and multiple correlation coefficients reveals that those for the accident cluster data are slightly larger and somewhat more significant than those for the road lengths. Better correlation should not be surprising since the slipperiness of the surface was measured by the stopping distance method which, of

necessity, yields data at a particular site. As previously stated, these sites were as close as practicable to the locations of the accident clusters. This slightly better correlation, although it is probably not significant, may suggest a preference for using the accident cluster as the basis of analysis rather than the road length.

Moreover, it must be considered that the test locations were chosen from a population stratified according to the SSR of the road lengths. This insured a sample that was distributed over the entire range of the SSR. Since the cluster which occurred on the previously selected road lengths did not, in general, have the same value for the SSR as did the entire road length, the data for the accident cluster analysis is not necessarily well distributed over the entire range of SSR. The resulting grouping at various levels of the SSR may well have caused the analysis to indicate less correlation than might be expected from a better distribution of the data. It would seem that the use of the accident cluster would also be advantageous since this would aid in the identification of particular locations and thereby facilitate economy through the application of corrective measures to relatively short lengths of roadway. This would be especially possible at intersections, both rural and urban. Figure 3 indicates such a possibility; for example, at the intersection of US 6 and SR 49 in Liberty Township. Figure 4 shows this to an even greater degree at the intersection of SR 9 and SR 15 (38th Street) south of Marion. At these and similar locations, the opportunity exists to eliminate the majority of the wet surface accidents by providing adequate resistance to skidding.

When the surface is relatively slippery for a considerable number

of miles, the wet surface skidding accidents may be distributed, but grouping may still be apparent; however, these groups will tend to be dispersed over a longer distance, perhaps as much as four or five miles.

Related Correlations

The correlation coefficients r_{12}, r_{13}, and r_{23} (shown in Table 8 of the Appendix) were not discussed in the preceding section since they are not directly related to the problem under investigation. However, some discussion of them is warranted and of interest.

The significant negative correlation between the slipperiness of the surface and the mean over-all speed is not too surprising. There is reason to suspect that the vehicle operators may have some knowledge of the relative slipperiness of the surfaces upon which they are driving and decrease or increase their speeds accordingly. The obvious case of course is where "slippery when wet" signs have been placed; such signs were present at only one of the locations tested however. Most important is the fact that in all probability, much of the traffic has traveled the route many times and experience as to the slippery conditions is often available to many of the drivers.

Geometric design, not included in this study, may also be one of the independent factors responsible for the decrease in speed as the distance required to stop increases. Highways that have low geometric design standards, which restrict speeds, often have lower type surfaces which provide less resistance to skidding.

No significant correlation was found to exist between the slipperiness of the surface and the average annual daily traffic. This is not unexpected in view of the various ages of the pavements and the different

types of pavement included in this study.

It is generally known that, for a particular highway, an increase in volume when the volume approaches or exceeds the practical capacity effects a decrease in speed. A similar relationship (i. e., the higher the volume the lower the speed) is also probably true for two or more highways which are homogeneous in all geometric aspects and when the volumes are in the vicinity of the practical capacity. This study, however, included highways of various geometric standards. Furthermore, at the time the data were collected, most of the facilities were operating considerably below capacity; thus, any inter-relationship between speed and volume would be minimized. For these reasons, the absence of significant negative correlation between speeds and the ADT is not unreasonable.

The relationships discussed in this section pertain equally to the road length and accident cluster data and analysis.

SUMMARY AND RECOMMENDATIONS

The conclusions and recommendations made from the data herein analyzed are as follows:

1. There is a very significant correlation between motor vehicle accidents which involve skidding on wet highway surfaces and the slipperiness of the surface.
2. Accident report analysis utilizing the procedures outlined in this study can be employed to indicate the relative slipperiness of roadway surfaces and can be effectively employed to identify troublesome slippery locations.
3. The use of accident clusters in the analysis for determining the location of slippery sites is superior to using the road length (i. e., a particular highway traversing a single township).
4. Skidding occurs in a very small percentage of wet surface accidents, regardless of the speed, when the surface exhibits a high resistance to skidding. Conversely, skidding occurs in a dangerously high percentage of wet surface accidents, regardless of the speed at which vehicles travel on the roadway, when the wet surface has a low resistance to skidding. For moderately slippery pavements, the percentage of wet surface accidents involving skidding increases as the speed at

which vehicles travel on the facility increases.

5. Traffic volumes need not be considered when establishing the priority for "de-slicking" various locations since it is automatically included in the significant skidding rate. A slippery surface having a very low volume will have, in general, a lower significant skidding rate than a slippery surface which carries a large volume. The locations having the highest SSR should have the highest priority for "de-slicking".
6. A location map of wet surface accidents is recommended as the most practical, flexible, and simplest method for identifying wet surface accident clusters and for obtaining the required data necessary to determine the significant skidding rate.
7. A system of mileposts properly established in the field and on the accident location map would be of value in accident analysis when effectively used to report accident locations. It would facilitate more accurate location and identification of relatively short and slippery sites.
8. It is recommended that proper "de-slicking" measures be performed at the slippery sites that have been noted in this study. It is further suggested that some of these sites be intersection approaches which have a high proportion of wet surface skidding accidents; these locations should be "de-slicked" for a relatively short distance, perhaps 300 to 500 feet. The accident history of all the "de-slicked" locations should be periodically analyzed to determine if wet surface

accidents, wet surface skidding accidents, and the significant skidding rates have been reduced.

9. It is recommended that slippery locations on state highways throughout the State of Indiana be determined at least once a year by the procedures outlined in this report and that high priority be given to the proper "de-slicking" of these locations.

POSSIBLE PROCEDURES FOR A STATE-WIDE ROUTE SKID ANALYSIS

Information Necessary

The first step necessary for locating slippery sites through analysis of accident reports is to obtain the following information:

(1) the locations at which accidents occurred,

(2) the total number of accidents which occurred at each location when the pavement surface was wet,

(3) the number of these accidents in which skidding occurred.

No differentiation should be made between skidding before or after braking; the number of accidents in which skidding occurred should be the total number of accidents in which skidding, before or after braking, was involved. However, care must be taken so as not to count an accident in which skidding occurred both before and after braking as two skidding accidents.

The sorting procedure which is followed in the process of tabulating this information is immaterial. Some of the possible methods and a few of their more important advantages and disadvantages are presented on the following pages.

Accident Location Map

The use of accident location maps is the best method for recording skidding accident data. Accidents must be shown as having occurred

on wet or other pavement conditions. Accidents which occurred on wet pavements should also be differentiated as to whether skidding did or did not occur. This information could be plotted on the accident map currently prepared by the State Highway Department of Indiana by using an appropriate legend. Visual inspection would then reveal those locations at which skidding accidents are grouping. A state-wide analysis, as developed in this study, could be performed as often as desired. Individual troublesome skidding locations could be analyzed as they become apparent.

Some difficulty might be encountered in the establishment of a satisfactory code that would provide the information necessary for a route skid analysis and also retain all of the information presently shown on the state accident map. If necessary, the information on whether skidding occurred could be omitted from the map. This information would then be obtained by again referring to the accident reports for locations where a number of accidents on wet surfaces are indicated by the map. This procedure would, of course, be time consuming.

Another technique would be to maintain a separate map upon which only wet surface accidents would be plotted. It would then be a very simple matter to differentiate between those accidents which involved skidding and those which did not.

From the experience of conducting this investigation, it was found that very little time is required to actually plot the accident locations. Since all reports are being handled at present, the additional time required to plot the information required for route skid analysis would be quite nominal.

The maintenance of one map for accident severity and another map for wet surface and skidding accidents would necessitate a minimum of information on any one map and would simplify visual analysis. This would be especially true where a large number of accidents occur in a relatively small area such as near the larger cities.

A separate location map of wet surface accidents might also be adapted so as to show the previous twelve months accidents rather than just those since January 1 of any particular year. This could be done, for example, by using pins with the numbers "1" through "12" indicated on them. In such a system, pins with square heads might represent wet surface accidents in which skidding was not involved. Pins with triangular heads could represent wet surface accidents in which skidding was involved. The numbers "1" through "12" would then denote the month in which the accident occurred. Then at the end of any month, the map could be studied to determine if any clusters existed. The pins representing the accidents during the earliest month of the preceding year would then be removed. For example, at the end of May, 1960, the pins marked with the number "6," representing accidents occurring during June, 1959, would be removed and used to represent June, 1960, accidents as reports of these current accidents are received. Such a procedure would permit an analysis to be made at the end of each month for a full twelve month accident history and at any time for accidents occurring during a minimum of eleven months.

When the resistance to skidding is increased at a previously slippery site, this fact should be clearly noted. Accidents occurring after the corrective measure has been completed would continue to be

plotted and the effectiveness of the "de-slicking" should be evaluated. The same procedure should be followed for any portion of a highway for which the surface characteristics are changed due to normal resurfacing or reconstruction.

For most efficient results, care must be exercised when plotting the accident locations. For example, since the analysis should indicate which of the approaches to an intersection are slippery, each location must be carefully plotted so as to indicate the proper approach on which each accident occurred instead of simply indicating that an accident occurred at a given intersection. Similarly, indication should be made as to the roadway on which each accident occurred when a multi-lane divided facility is involved. This can easily be done by simply positioning the pins on the proper side of the line representing the highway on the map.

The present location information on the accident reports, as stated in a previous section of this study, is of questionable accuracy. However, it is probably as good as can be expected until a systematic location system is developed. The establishment of mileposts along the highway, and their use for giving location on the accident report would facilitate accurate location of accidents. This would permit much more accurate determination of the location of skidding accident clusters and thereby promote more efficient application of "de-slicking" treatments.

Although mileposts would have to be established, it is not believed that this would be an important factor. A system of mileposts could have other uses than facilitating accident reporting. They would not be as expensive to establish and maintain, as it would first appear if the posts were also used for other purposes; for example, the State

of Texas uses the mileposts to support route markers.

Mechanical Methods

Even if a route skid analysis accident map is not established, a procedure for locating slippery sections of road can be developed. Such a procedure would involve a tabulation of the desired information from the accident reports for a period of time by manual or mechanical sorting and counting. Manual sorting and tabulation is not practical for the entire state and will not be discussed further.

If, for mechanical sorting, the locations of accidents are coded by route and township, the total number of accidents occurring on wet surfaces and the number of these accidents which involve skidding could be tabulated for each route within a township. The significant skidding rate could then be determined from Table 2 of this report for each length of highway.

The required data could be tabulated in conjunction with currently made quarterly and end of year summaries and would require a minimum of extra machine operation. Furthermore, no change in present coding procedures would be necessary. However, the original accident reports would have to be manually reviewed in order to determine more specific locations at which skidding accidents were occurring on wet surfaces for those routes where an undesirably high percentage of skidding accidents were occurring. Moreover, manual review of the accident reports have to be given those road lengths which follow a township line and/or are traversed by two or more routes for part of their length.

The coding of accidents by route and township requires that the accident reports be manually reviewed to determine specific locations.

This disadvantage can be overcome, at least in part, if a system of mileposts were established and used to report accident locations as well as for the coding of the locations.

The total number of accidents occurring on wet surfaces and the number of these accidents in which skidding was involved could then be mechanically tabulated for each mile or other desired length.

BIBLIOGRAPHY

List of References

1. Giles, C. G., and Sabley, Barbara E., "Accident Reports and Skidding Accident Sites," A *Reprint* from The Public Works and Municipal Works Congress, November, 1956.

2. Sabley, Barbara E., "Accident Reports as a Guide to Slippery Lengths of Road," A *Reprint* from Roads and Road Construction, July, 1956.

3. The Report of the Road Research Board with the Report of the Director of Road Research, *Road Research 1955*, Department of Scientific and Industrial Research, p. 21, 1956.

4. Petring, F. William, "Stopping Ability of Motor Vehicles Selected from the General Traffic," *Public Roads*, Vol. 29, No. 8, p. 195, June, 1957.

5. The Staff of the Computational Laboratory, "Tables of the Cumulative Probability Distribution," *The Annals of the Computational Laboratory of Harvard University*, Vol. XXXV, Harvard University Press, 1955.

6. Michael, H. L., and Grunau, D. L., "Development of Skid Testing in Indiana," *Report* No. 13, Joint Highway Research Project, Purdue University, 1956, also *Bulletin* No. 139, Highway Research Board, 1956.

7. Ostle, Bernard, *Statistics In Research*, The Iowa State College Press, 1954.

8. Walker, William P., "Speed and Travel Time Measurement in Urban Areas," *Bulletin* No. 156, Highway Research Board, 1956.

9. Stohner, Walter R., "Speeds of Passenger Cars on Wet and Dry Pavements," *Bulletin* No. 139, Highway Research Board, 1956.

General References

1. "Application of Skid Resistant Surfaces to Highways," Bulletin No. 188, Highway Research Board, 1958.

2. Bennett, Carl A. and Franklin, Norman L., Statistical Analysis in Chemistry and the Chemical Industry, John Wiley and Sons, 1954.

3. Committee on Uses of Developed Information, Uses of Traffic Accident Records, Eno Foundation for Highway Traffic Control, Inc., pp. 73-107, 169, 1947.

4. "Development of New Non-Skid Road Surface Treatment," Bulletin No. 184, Highway Research Board, 1958.

5. "Pavement Slipperiness Factors and Their Measurement," Bulletin No. 186, Highway Research Board, 1958.

6. Proceedings, First International Skid Prevention Conference, Parts I and II, Virginia Council of Highway Investigation and Research, August, 1959.

7. "Roughness and Skid Resistance," Bulletin No. 37, Highway Research Board, 1951.

8. Shupe, J. W. and Goetz, W. H., "A Laboratory Method for Determining Skidding Characteristics of Bituminous Paving Mixtures," A Reprint from the Proceedings of the American Society for Testing Materials, 1958.

9. Stephens, Jack Edward, "A Laboratory Investigation of the Phenomenon of Friction as Applied to Fine-Textured Bituminous Paving Mixtures," A Thesis submitted to Purdue University for the Degree of Doctor of Philosophy, 1959.

10. The Report of the Road Research Board with the Report of the Director of Road Research, Road Research 1956, Department of Scientific and Industrial Research, pp. 12-17, 1957.

11. Tutt, Paul R. and Welty, William R., "Highway Accident Analysis Through Use of IBM Punch Cards," Bulletin No. 142, Highway Research Board, 1956.

12. Vick, Alfred, III, "Virginia's Cooperative Accident Analysis System," Bulletin No. 142, Highway Research Board, 1956.

13. Webb, G. M., "Accident Study," Traffic Engineering, Vol. 29, No. 1, pp. 18-20, 62, October, 1958.

14. Woo, John C. H., "Correlation of Accident Rates and Roadway Factors," A Thesis submitted to Purdue University for the Degree of Master of Science in Civil Engineering, 1957.

APPENDIX

BASIS OF THE SIGNIFICANT SKIDDING RATE

The theoretical basis for the calculation of the significant skidding rate is the binomial distribution. The binomial is the distribution of the number of occurrences of a random variable which exhibits a particular characteristic with probability "p" and does not exhibit this characteristic with probability "1-p". Such a situation arises when the result of a given trial can be classified as a success or a failure; a given item can be classified as defective or non-defective; or a given characteristic is observed or is not observed. The distribution depends only upon the fixed number of n independent trials and the fixed probability "p" of the event occurring on each trial.

In regard to skidding accidents on wet surfaces, the occurrence of an accident which did not involve skidding might be classified as a success or a non-defective, since the characteristic of skidding was not observed. Likewise, a wet surface accident which involved skidding might be classified as a failure or a defective since the characteristic of skidding was observed.

Let n represent the total number of wet surface accidents. For each accident the probability of success (i. e., skidding is not involved) is 1-p and the probability of failure (i. e., skidding is involved) is p. Since the accidents are independent, the probability of obtaining any particular sequence of x failures and n-x successes will be the product

of the individual probability of a failure in x cases and the probability of a success in n-x cases. The probability of exactly x skidding accidents, regardless of the order in which they occur, is given by $P(x) = \binom{n}{x}p^x (1-p)^{n-x}$. The binomial distribution thereby gives the probability for any given number of occurrences of an event in n trials when the probability for any one trial is p. Thus, if the probability of skidding being involved in wet surface accidents is 0.30 at a given location then ten such accidents would be expected to have skidding involved in three of them. However, skidding could occur in all or none of the ten accidents. The binomial distribution tells how often the expected three will occur. The probability of exactly three is 0.267 and the probability of three or more is 0.617 in ten accidents in which the probability of skidding in any one accident is 0.30.

Rather than calculate the total number of wet surface accidents from the above formula, the Harvard Tables (4) were used. By assuming various values for x and the SSR (given as r and p respectively in the tables), while maintaining the significance level at 5% for a one-tail test, the required values of n were determined from the tables. Thus, for example, if x equals six, the skidding rate is significantly greater than 30% if n is less than eleven. In order to utilize the table so as to have the total number of accidents observed less than that number given in the table all values in the body of the table were increased by one. In the above example the value thus shown in the table is twelve rather than eleven.

CALCULATIONS

Road Lengths

The raw data for the road lengths are presented in Table 1. Table 2 indicates the method employed in the calculation of the simple regression coefficients and symbolizes the numbers contained in Tables 3 and 6. The procedure for working such a table is presented in the text by Ostle.

The simple correlation coefficients, the r_{iy} values, indicated in Table 3 are measures of the gross degree of dependence between the two characteristics being considered which may include influence of other variables. A partial correlation coefficient indicates the degree of linear association after eliminating any linear tendency of these other variables to affect jointly the factors under consideration. Thus, the partial correlation coefficient $r_{y1.2}$ indicates the degree of linear association between the SSR and the slipperiness of the surface after elimination of any linear tendency of the mean over-all speed to affect jointly the two factors being considered. The degree of linear association between the SSR and the slipperiness of the surface after the elimination of any linear tendency of the ADT to affect jointly them is indicated by $r_{1y.3}$. The partial correlation coefficient $r_{y1.23}$ indicates the degree of linear association between the SSR and the slipperiness of the road surface after eliminating any linear tendency of the mean over-all speed and the ADT to affect jointly the above two factors. For the

road length data:

$$r_{y1.2} = \frac{r_{y1} - (r_{y2})(r_{12})}{\sqrt{1 - r_{y2}^{2}}\ \sqrt{1 - r_{12}^{2}}} = 0.7980$$

$$r_{y1.3} = \frac{r_{y1} - (r_{y3})(r_{13})}{\sqrt{1 - r_{y3}^{2}}\sqrt{1 - r_{13}^{2}}}$$

$$r_{y1.23} = \frac{r_{y1.2} - (r_{y3.2})(r_{13.2})}{\sqrt{1 - r_{y3.2}^{2}}\ \sqrt{1 - r_{13.2}^{2}}} = 0.7982$$

The multiple correlation coefficient, R, measures the degree of joint linear association among all the factors under consideration. The value of R^2 is the proportion of the total variation in the SSR as explained by the multiple regression and may be calculated by the formula:

$$R_{y.123}^{2} = \sum b_i^{*}\ r_{iy}$$

For the road length data:

$$R_{y.123}^{2} = 0.7285$$

$$R_{y.123} = 0.8535$$

Significance test on R:

$$F_{k,n - k - 1} = \frac{R^2/_k}{(1 - R^2)/_{n - k - 1}} = 15.205$$

$$F_{3,17} > F_{3,17,0.005} = 6.156$$

Thus, R is highly significant and approximately 73% of the variation in the SSR is accounted for by the slipperiness of the surface, the mean over-all speed, and the average annual daily traffic.

The significance of the r_{iy} values might be tested by the following:

$$t_n = 2 = \frac{r_{ij}}{\sqrt{1 - r_{ij}^2}} \sqrt{n - 2}$$

If $t_{n - 2} > t_{n - 2, \alpha}$ the value of r_{iy} is significant at the α level of significance. Although all of the assumptions upon which this test is based may not be met by this data the test is the best that is available. The results of the tests of significance are given in Table 8.

The regression coefficients, b_i, are obtained from:

$$b_i = b_i^* \frac{S_y}{S_{x_i}}$$

For the road length data:

$$b_1 = (0.8551)\frac{80.754}{69.156} = 1.4341$$

$$b_2 = (0.3515)\frac{80.754}{33.760} = 0.8428$$

$$b_3 = (0.2979)\frac{80.754}{16.508} = 1.4573$$

The significance of the regression coefficients can be tested by:

$$t_{n-k-1} = \frac{b_i^*}{S_{b_i^*}}$$

Where:

$$S_{b_i^*} = \sqrt{\frac{(1 - R^2)}{n - k - 1} \quad c_{ii}^*}$$

And:

$$c_{33}^* = 1.1052$$

$$c_{22}^* = 1.4390 - (-0.0273)(0.0302) = 1.4398$$

$$c_{11}^* = 1.0000 - (-0.5524)(0.7161) - (0.3077)(0.0302) = 1.3863$$

Substitution of R^2 and the c_{ii}^* values into the above formula gives:

	Locat
Route	Cour
US 12	Porte
SR 60	Lawren
US 52	Tippec
SR 37	Grant
SR 267	Hendri
US 35	Grant
SR 49	Porter
US 35	Grant
US 50	Lawren
US 231	Putna
SR 26	Tippec
SR 130	Porte
US 40	Hendri
US 20	Porte
SR 25	Tippec
SR 9	Grant
US 231	Putna
US 40	Putna
SR 49	Porter
US 40	Putna
US 52 By-Pass	Tippec

TABLE 1

ROAD LENGTH CORRELATION DATA

Location			SSR by Road Lengths (y)	Average Distance Required to Stop From 30 MPH (x_1)	Mean Over All Speed in MPH (x_2)	ADT (thousands) (x_3)
Route	County	Township				
US 12	Porter	Portage	0	49.8	48.8	5.3
SR 60	Lawrence	Marion	0	55.6	52.8	0.6
US 52	Tippecanoe	Sheffield	NS	56.7	60.7	7.1
SR 37	Grant	Liberty	NS	64.5	58.7	4.3
SR 267	Hendricks	Washington	5	72.1	43.1	0.7
US 35	Grant	Jefferson	9	77.8	46.9	1.5
SR 49	Porter	Westchester	13	85.1	43.2	5.0
US 35	Grant	Mill	15	84.5	46.9	1.7
US 50	Lawrence	Marion	20	65.8	52.9	2.2
US 231	Putnam	Cloverdale	20	98.2	44.0	2.5
SR 26	Tippecanoe	Fairfield	25	80.2	52.2	2.5
SR 130	Porter	Union	25	85.2	51.9	3.2
US 40	Hendricks	Franklin	30	78.8	56.9	7.6
US 20	Porter	Westchester	30	75.1	54.1	12.0
SR 25	Tippecanoe	Washington	40	77.6	52.8	4.5
SR 9	Grant	Center	40	97.8	38.2	13.0
US 231	Putnam	Greencastle	45	103.6	47.7	3.5
US 40	Putnam	Marion	45	78.5	59.6	6.6
SR 49	Porter	Liberty	50	90.7	45.3	5.0
US 40	Putnam	Warren	50	91.5	59.3	6.5
US 52 By-Pass	Tippecanoe	Fairfield	50	105.8	31.1	12.5

TABLE 2

COMPUTATION OF r_{iy} VALUES FOR A MULTIPLE REGRESSION EQUATION

	X_1	X_2	X_3	Y
	ΣX_1	ΣX_2	ΣX_3	ΣY
	$\Sigma X_1/n$	$\Sigma X_2/n$	$\Sigma X_3/n$	$\Sigma Y/n$
X_1	ΣX_1^2	ΣX_1X_2	ΣX_1X_3	ΣX_1Y
	$(\Sigma X_1)^2/n$	$(\Sigma X_1)(\Sigma X_2)/n$	$(\Sigma X_1)(\Sigma X_3)/n$	$(\Sigma X_1)(\Sigma Y)/n$
	Σx_1^2	Σx_1x_2	Σx_1x_3	Σx_1y
	Σx_1	$\Sigma x_1 \quad \Sigma x_2$	$\Sigma x_1 \quad \Sigma x_3$	$\Sigma x_1 \quad \Sigma y$
	$r_{11} = 1$	r_{12}	r_{13}	r_{1y}
		r_{12}^2	r_{13}^2	r_{1y}^2
X_2		ΣX_2^2	ΣX_2X_3	ΣX_2Y
		$(\Sigma X_2)^2/n$	$(\Sigma X_2)(\Sigma X_3)/n$	$(\Sigma X_2)(\Sigma Y)/n$
		Σx_2^2	Σx_2x_3	Σx_2y
		Σx_2	$\Sigma x_2 \quad \Sigma x_3$	$\Sigma x_2 \quad \Sigma y$
		$r_{22} = 1$	r_{23}	r_{2y}
			r_{23}^2	r_{2y}^2
X_3			ΣX_3^2	ΣX_3Y
			$(\Sigma X_3)^2/n$	$(\Sigma X_3)(\Sigma Y)/n$
			Σx_3^2	Σx_3y
			Σx_3	$\Sigma x_3 \quad \Sigma y$
			$r_{33} = 1$	r_{3y}
				r_{3y}^2

TABLE 2 (Continued)

	X_1	X_2	X_3	Y
Y				ΣY^2 $(\Sigma Y)^2/n$ Σy^2 Σy

TABLE 3

COMPUTATION OF CORRELATION COEFFICIENTS BETWEEN ROAD LENGTH DATA*

	X_1	X_2	X_3	Y
n = 21	1,674.9 79.7571	1,047.1 49.8619	107.8 5.1333	514.0 24.4762
X_1	138,367.65 133,585.17 4,782.48 69.156	82,224.63 83,513.69 -1,289.06 2,334.71 -0.5524 0.3051	8,949.07 8,597.76 351.31 1,141.63 0.3077 0.0947	45,198.20 40,995.19 4,203.01 5,584.62 0.7526 0.5664
X_2		53,350.13 52,210.40 1,139.73 33.760	5,269.76 5,375.07 -105.31 557.31 -0.1890 0.0357	25,146.10 25,629.02 -482.92 2,726.26 -0.1771 0.0314
X_3			825.88 553.37 272.51 16.508	3,297.90 2,638.53 659.37 1,333.09 0.4946 0.2446
Y				19,102.00 12,580.77 6,521.23 80.754

---

* Entries correspond to Table 2.

TABLE 4

COMPUTATION OF THE STANDARD REGRESSION COEFFICIENTS FOR THE ROAD LENGTH DATA

	X_1	X_2	X_3	Y	C_{i1}	C_{i2}	C_{i3}	Check
X_1	1.0000	-0.5524	0.3077	0.7526	1.0000	0.0000	0.0000	2.5079
X_2		1.0000	-0.1890	-0.1771	0.0000	1.0000	0.0000	1.0815
X_3			1.0000	0.4946	0.0000	0.0000	1.0000	2.6133
A_1	1.0000	-0.5524	0.3077	0.7526	1.0000	0.0000	0.0000	2.5079
B_1	1.0000	-0.5524	0.3077	0.7526	1.0000	0.0000	0.0000	2.5079
A_2		0.6949	-0.0190	0.2386	0.5524	1.0000	0.0000	2.4669
B_2		1.0000	-0.0273	0.3434	0.7949	1.4390	0.0000	3.5500
A_3			0.9048	0.2695	-0.2926	0.0273	1.0000	1.9090
B_3			1.0000	0.2979	-0.3234	0.0302	1.1052	2.1099

$$b_3^* = 0.2979$$

$$b_2^* = (0.3434) - (-0.0273)(0.2979) = 0.3515$$

$$b_1^* = (0.7526) - (-0.5524)(0.3515) - (0.3077)(0.2979) = 0.8551$$

$$S_{b_1^*} = \sqrt{\frac{(1 - 0.7285)\ (1.3863)}{21 - 3 - 1}} = 0.1488$$

$$S_{b_2^*} = 0.1517$$

$$S_{b_3^*} = 0.1329$$

The results of the test of significance are given in Table 9.

Accident Clusters

The raw data by accident clusters is presented in Table 5. The analysis parallels that previously performed on the road length data and is indicated in Tables 6 and 7. For the accident cluster information, the partial correlation coefficient, $r_{y1.23}$, of the SSR and the slipperiness of the surface independent of the mean over-all speed and the ADT is 0.7709, $r_{y1.2} = 0.7445$, and $r_{y1.3} = 0.7437$.

The multiple correlation coefficient and its square are:

$$R = 0.8561$$

$$R^2 = 0.7330$$

The significance tests on R yields:

$$F_{3,17} = 15.56 > F_{3,17,0.005} = 6.156$$

Thus, the value of R is very highly significant, at the 0.005 level and approximately 73% of the variation in the SSR of the accident clusters is accounted for by the slipperiness of the surface, the mean

over-all speed, and the ADT.

The following values for the accident cluster data were obtained in the same manner as the corresponding values for the road length data:

$$b_1 = (0.7223) \frac{83.326}{70.312} = 0.8560$$

$$b_2 = (0.2019) \frac{83.326}{33.760} = 0.4983$$

$$b_3 = (0.4127) \frac{83.326}{17.565} = 1.9578$$

	L
Route	Cou
US 12	Por
SR 60	Law
US 52	Tip
SR 37	Gra
SR 267	Hen
US 35	Gra
SR 49	Por
US 35	Gra
US 50	Law
US 231	Put
SR 26	Tip
SR 130	Por
US 40	Hen
US 20	Por
SR 25	Tip
SR 9	Gra
US 231	Put
US 40	Put
SR 49	Por
US 40	Put
US 52 By-Pass	Tip

TABLE 5

ACCIDENT CLUSTER CORRELATION DATA

Location			SSR by Accident Cluster	Average Distance Required to Stop from 30 MPH (X_1)	Mean Over-All Speed in MPH (X_2)	ADT (thousands) (X_3)
Route	County	Township				
US 12	Porter	Portage	0	49.8	48.8	5.3
SR 60	Lawrence	Marion	0	55.6	52.8	0.6
US 52	Tippecanoe	Sheffield	NS	56.7	60.7	7.1
SR 37	Grant	Liberty	NS	64.5	58.7	4.3
SR 267	Hendricks	Washington	9	72.1	43.1	0.7
US 35	Grant	Jefferson	15	77.8	46.9	1.5
SR 49	Porter	Westchester	15	85.1	43.2	5.0
US 35	Grant	Mill	13	84.5	46.9	1.7
US 50	Lawrence	Marion	NS	65.8	52.9	2.2
US 231	Putnam	Cloverdale	15	98.2	44.0	2.9
SR 26	Tippecanoe	Fairfield	20	80.2	52.2	3.0
SR 130	Porter	Union	13	85.2	51.9	3.3
US 40	Hendricks	Franklin	35	86.4	56.9	3.8
US 20	Porter	Westchester	20	75.1	54.1	13.3
SR 25	Tippecanoe	Washington	50	77.6	52.8	4.3
SR 9	Grant	Center	50	97.8	38.2	12.5
US 231	Putnam	Greencastle	35	103.6	47.7	4.0
US 40	Putnam	Marion	35	91.6	59.6	3.3
SR 49	Porter	Liberty	45	90.7	45.3	5.3
US 40	Putnam	Warren	50	91.5	59.3	7.0
US 52 By-Pass	Tippecanoe	Fairfield	50	105.8	31.1	14.4

TABLE 6

COMPUTATION OF CORRELATION COEFFICIENTS BETWEEN ACCIDENT CLUSTER DATA*

	X_1	X_2	X_3	Y
n = 21	1,695.6 80.7429	1,047.1 49.8619	105.5 5.0238	473.0 22.5238
X_1	141,851.48 136,907.66 4,943.82 70.312	83,437.83 84,545.84 -1,108.01 2,373.73 -0.4668 0.2179	8,909.58 8,518,35 391.23 1,235.03 0.3168 0.1004	42,637.00 38,191.39 4,445.61 5,858.82 0.7588 0.5758
X_2		53,350.13 52,210.40 1,139.73 33.760	5,073.21 5,260.43 -187.22 592.99 0.3157 0.0997	22,837.60 23,584.67 -747.07 2,813.09 -0.2656 0.0705
X_3			838.53 530.01 308.52 17.565	3,221.90 2,376.26 1,845.64 1,463.62 0.5778 0.3339
Y				17,597.00 10,653.76 6,943.24 83.326

* Entries correspond to Table 2.

TABLE 7

COMPUTATION OF THE STANDARD REGRESSION COEFFICIENTS FOR THE ACCIDENT CLUSTER DATA

	X_1	X_2	X_3	Y	C_{i1}	C_{i2}	C_{i3}	Check
X_1	1.0000	-0.4668	0.3168	0.7588	1.0000	0.0000	0.0000	2.6088
X_2		1.0000	-0.3157	-0.2656	0.0000	1.0000	0.0000	0.9519
X_3			1.0000	0.5778	0.0000	0.0000	1.0000	2.5789
A_1	1.0000	-0.4668	0.3168	0.7588	1.0000	0.0000	0.0000	2.6088
B_1	1.0000	-0.4668	0.3168	0.7588	1.0000	0.0000	0.0000	2.6088
A_2		0.7821	-0.1678	0.0886	0.4668	1.000	0.0000	2.1697
B_2		1.0000	-0.2146	0.1133	0.5969	1.2786	0.0000	2.7742
A_3			0.8635	0.3564	-0.2166	0.2145	1.0000	2.2179
B_3			1.0000	0.4127	-0.2508	0.2484	1.1581	2.5685

$$b_3^* = 0.4127$$

$$b_2^* = (0.1133) - (-0.2146)(0.4127) = 0.2019$$

$$b_1^* = (0.7588) - (-0.4668)(0.2019) - (0.3168)(0.4127) = 0.7223$$

$c_{33}^{*} = 1.1581$

$c_{22}^{*} = 1.2786 - (-0.2146)(0.2484) = 1.3319$

$c_{11}^{*} = 1.0000 - (-0.4668)(0.5431) - (0.3619)(-0.2508) = 1.3443$

$S_{b_1}^{*} = 0.1453$

$S_{b_2}^{*} = 0.1446$

$S_{b_3}^{*} = 0.1349$

The results of the significance tests on the r_{iy} values calculated in Table 6 are given in Table 8. The results of the significance tests on the regression coefficients, b_i, are indicated in Table 9.

TABLE 8

SIGNIFICANCE TESTS ON THE SIMPLE CORRELATION COEFFICIENTS

	Source of Correlation	r_{iy}	r_{iy}^2	t_{n-2}	Significance Level
	Road Lengths				
r_{y1}	SSR - Distance to Stop	0.7526	0.5664	4.982	0.005
r_{y2}	SSR - Mean Over-all Speed	-0.1771	0.0314	0.784	0.500
r_{y3}	SSR - Average Annual Daily Traffic	0.4946	0.2446	2.481	0.025
r_{12}	Distance to Stop - Mean Over-all Speed	-0.5524	0.3051	2.889	0.010
r_{13}	Distance to Stop - Average Annual Daily Traffic	0.3077	0.0947	1.410	0.250
r_{23}	Mean Over-all Speed - Average Annual Daily Traffic	-0.1890	0.0357	0.839	0.500
	Accident Clusters				
r_{y1}	SSR - Distance to Stop	0.7588	0.5758	5.078	0.005
r_{y2}	SSR - Mean Over-all Speed	-0.2656	0.0705	1.201	0.250
r_{y3}	SSR - Average Annual Daily Traffic	0.5778	0.3339	3.086	0.010
r_{12}	Distance to Stop - Mean Over-all Speed	-0.4663	0.2179	2.602	0.025
r_{13}	Distance to Stop - Average Annual Daily Traffic	0.3168	0.1004	1.456	0.250
r_{23}	Mean Over-all Speed - Average Annual Daily Traffic	-0.3157	0.0997	1.450	0.250

TABLE 9

SUMMARY OF SIGNIFICANCE TESTS ON THE REGRESSION COEFFICIENTS

b_i	t_{17}	Significance Level
for road lengths		
b_1	5.747	0.005
b_2	2.317	0.050
b_3	2.242	0.050
for accident clusters		
b_1	4.971	0.005
b_2	1.396	0.250
b_3	3.059	0.010

α	0.500	0.250	0.100	0.050	0.025	0.010	0.005
$t_{17,\alpha}$	0.689	1.191	1.740	2.111	2.458	2.898	3.223

$$t_{17} = \frac{b_i^*}{S_{b_i}^*}$$